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(71) Applicant(s)
Sharp Kabushiki Kaisha
(Incorporated in Japan)
22-22 Nagaike-cho, Abeno-ku, Osaka 545-8522, Japan

(72) Inventor(s)
Adrian Marc Simon Jacobs

(74) Agent and/or Address for Service
Marks & Clerk
4220 Nash Court, Oxford Business Park South,
OXFORD, OX4 2RU, United Kingdom

(51) INT CL^6
G02F 1/1335

(52) UK CL (Edition P)
G2F FSX F23E F24T F25F

(56) Documents Cited
GB 2296099 A EP 0397263 A EP 0348964 A
US 5049427 A

(58) Field of Search
UK CL (Edition O) G2F FSX
INT CL^6 G02B 5/30, G02F 1/1335
ONLINE: WPI INSPEC

(54) Abstract Title
Liquid crystal device

(57) A method is provided of making a cell wall (1 to 5) of a liquid crystal spatial light modulator (1 to 11). The cell wall comprises a substrate (1) above which is formed a polariser (3) made of a polymer with conjugated double bonds. An alignment layer (5) is formed above the polariser (3) relative to the substrate (1). The conditions during manufacture are such that the performance of the polariser (3) is not excessively degraded. It is thus possible to provide a liquid crystal device containing an internal polariser and having acceptable performance.

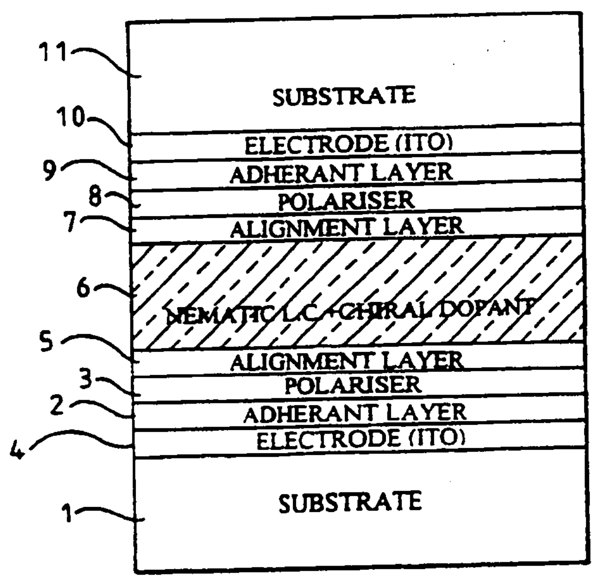


FIG 1

GB 2 326 727 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

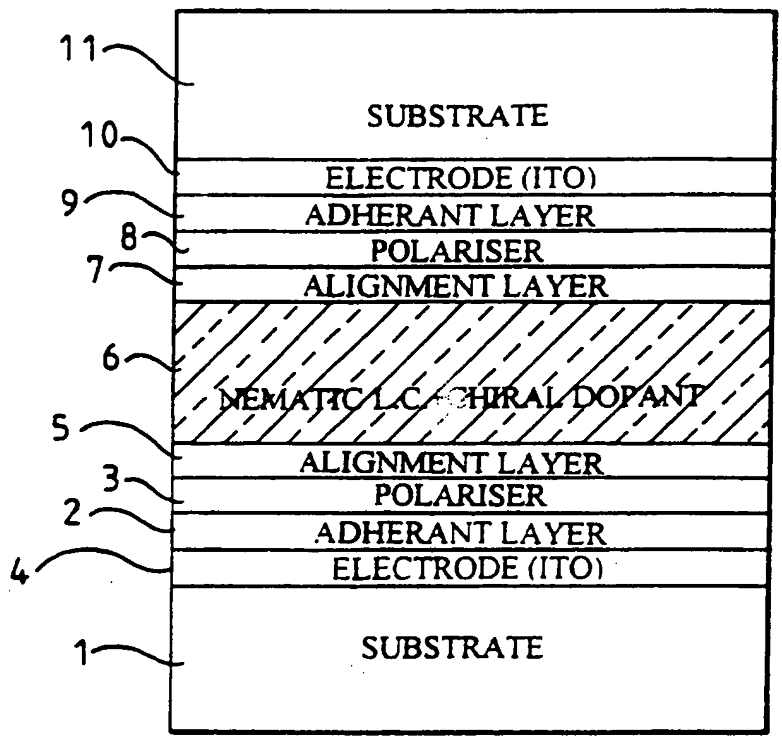

11
SUBSTRATE
10
ELECTRODE (ITO)
9
ADHERANT LAYER
8
POLARISER
7
ALIGNMENT LAYER
6
NEMATIC L.C.+CHIRAL DOPANT
5
ALIGNMENT LAYER
3
POLARISER
2
ADHERANT LAYER
4
ELECTRODE (ITO)
1
SUBSTRATE

FIG 1

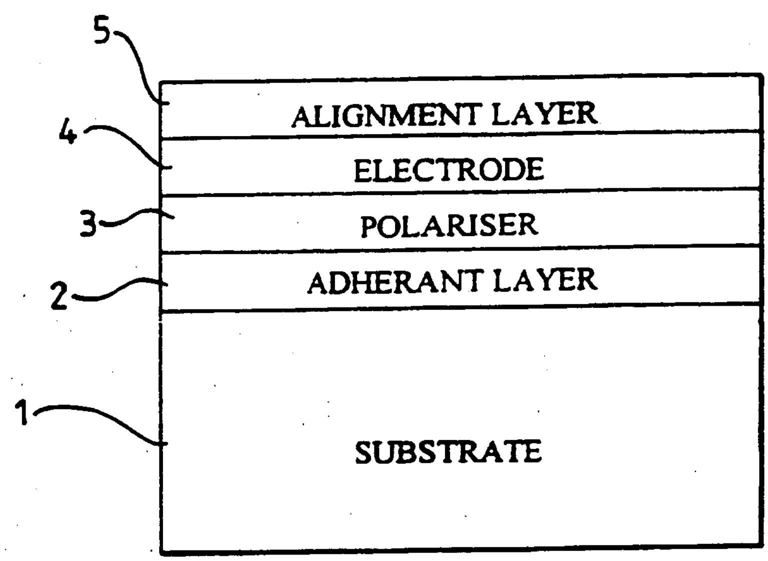

5
4
3
2
1
ALIGNMENT LAYER
ELECTRODE
POLARISER
ADHERANT LAYER
SUBSTRATE

FIG 2

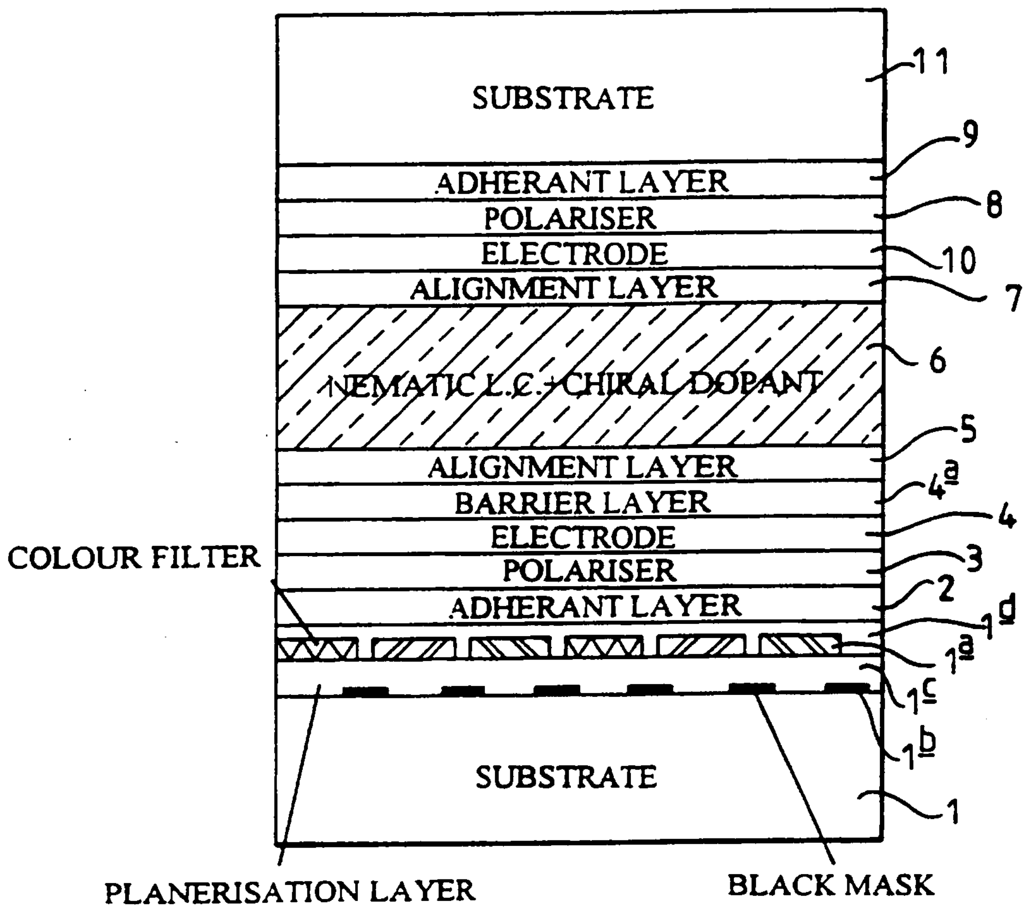

SUBSTRATE
11
ADHERANT LAYER
9
POLARISER
8
ELECTRODE
10
ALIGNMENT LAYER
7
NEMATIC L.C.+CHIRAL DOPANT
6
ALIGNMENT LAYER
5
BARRIER LAYER
4a
ELECTRODE
4
COLOUR FILTER
POLARISER
3
ADHERANT LAYER
2
1d
1a
1c
1b
SUBSTRATE
1
PLANERISATION LAYER
BLACK MASK

FIG 3

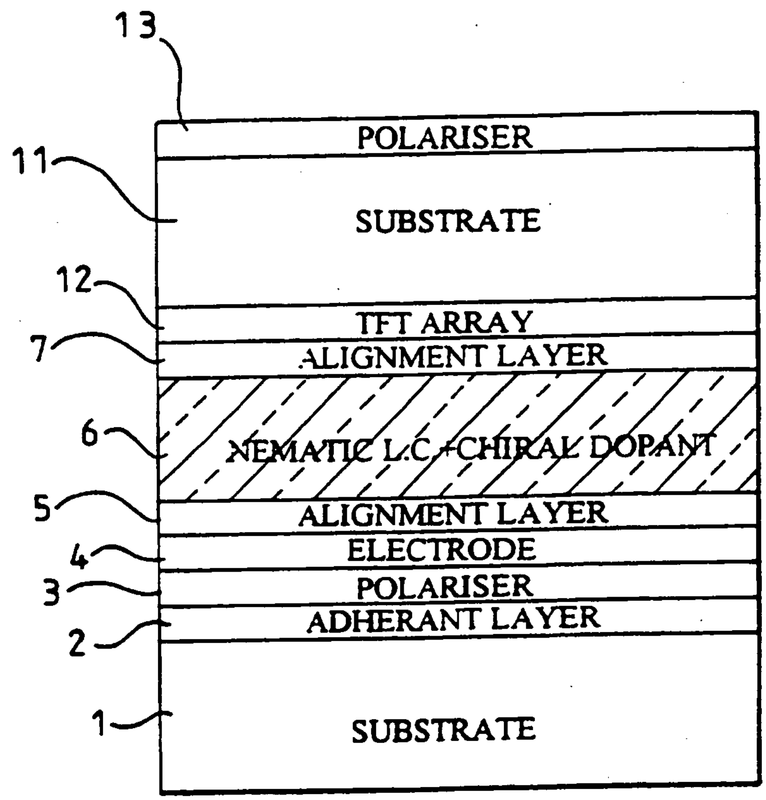

13
POLARISER
11
SUBSTRATE
12
TFT ARRAY
7
ALIGNMENT LAYER
6
NEMATIC L.C.+CHIRAL DOPANT
5
ALIGNMENT LAYER
4
ELECTRODE
3
POLARISER
2
ADHERANT LAYER
1
SUBSTRATE

FIG 4

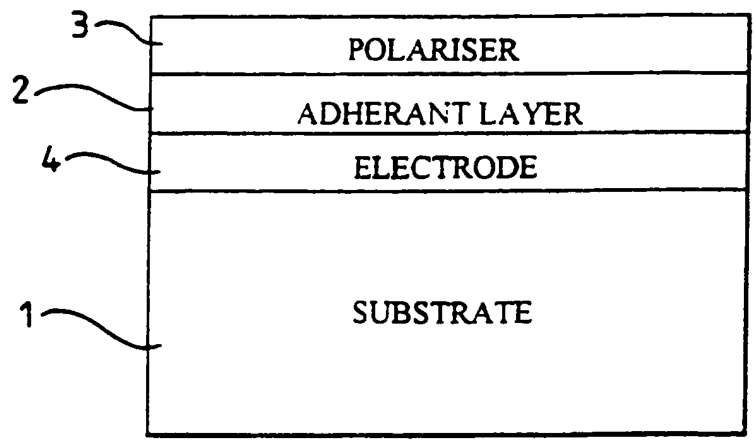


FIG 5

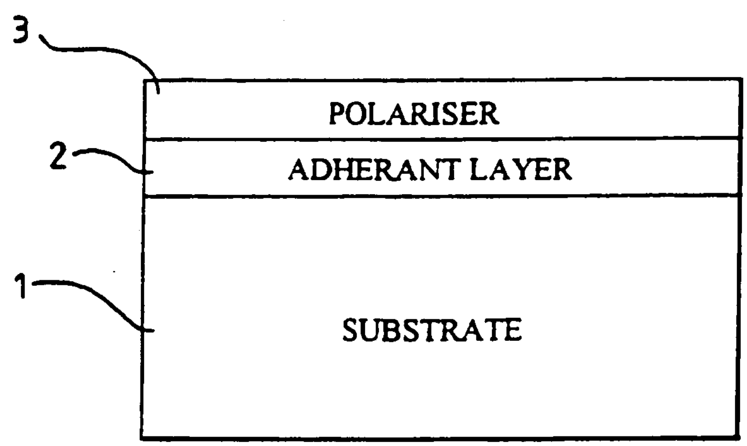


FIG 6

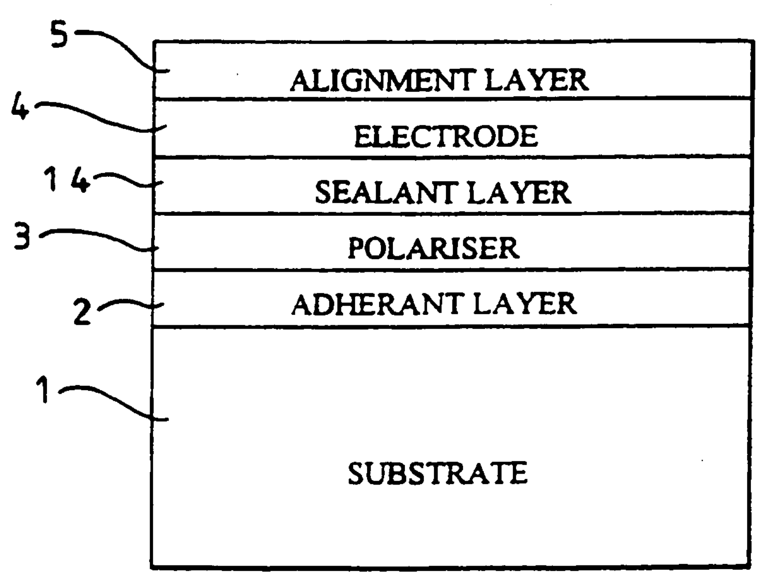


FIG 7

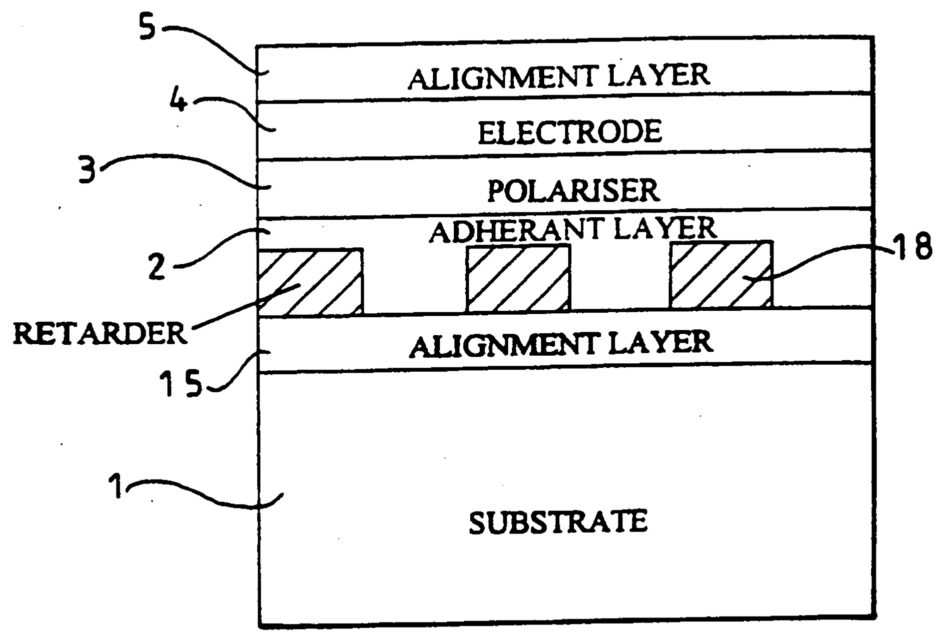

5
ALIGNMENT LAYER
4
ELECTRODE
3
POLARISER
ADHERANT LAYER
2
18
RETARDER
ALIGNMENT LAYER
15
1
SUBSTRATE

FIG 8

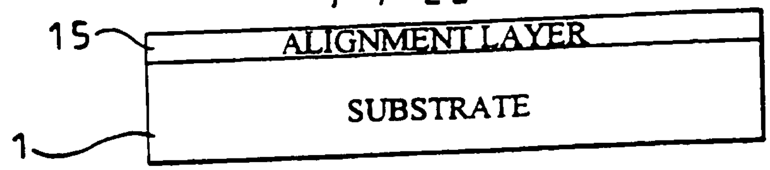


FIG 9a

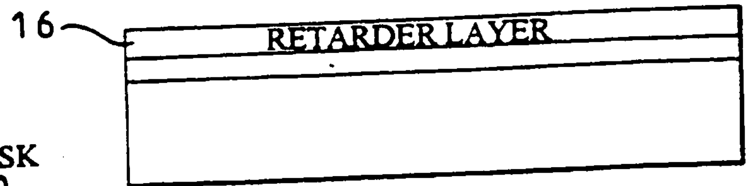


FIG 9b

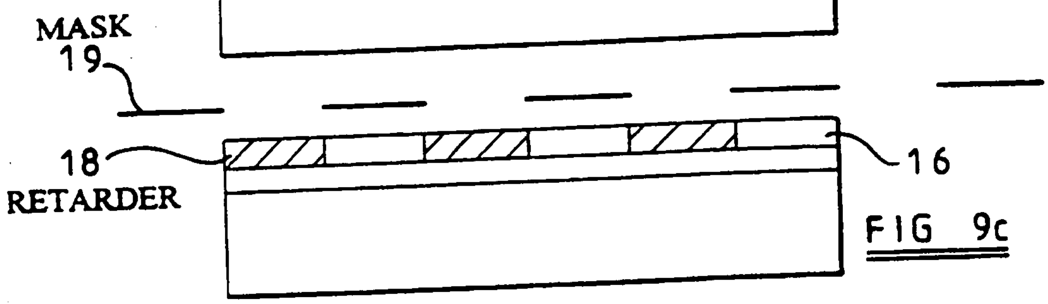


FIG 9c

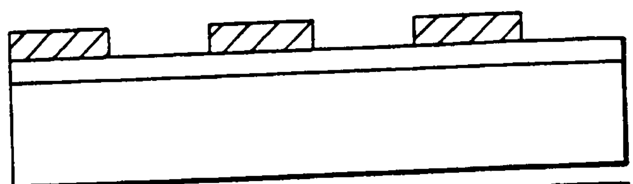


FIG 9d

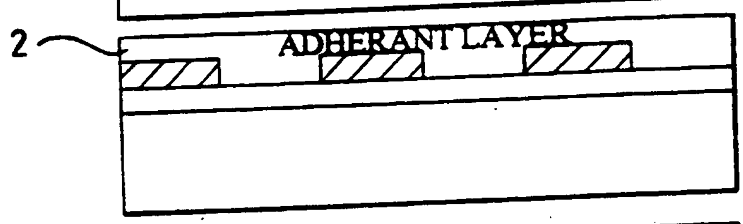


FIG 9e

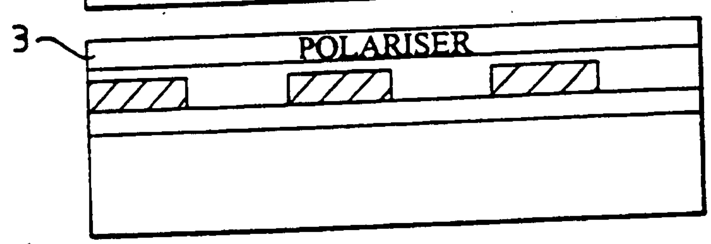


FIG 9f

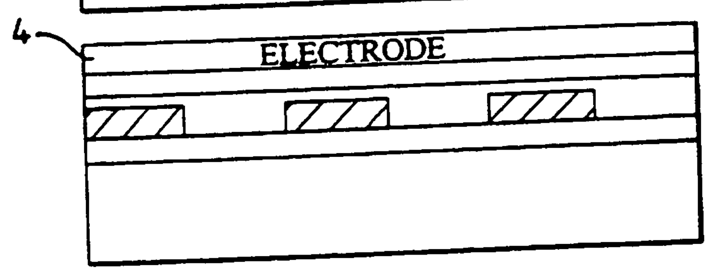


FIG 9g

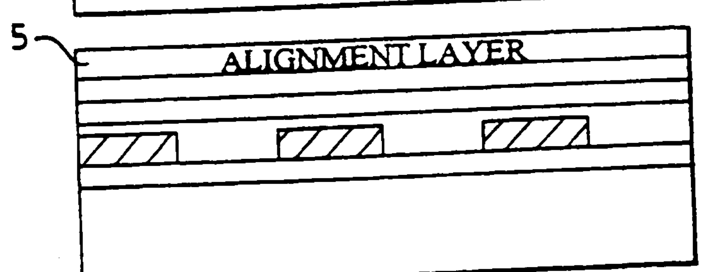


FIG 9h

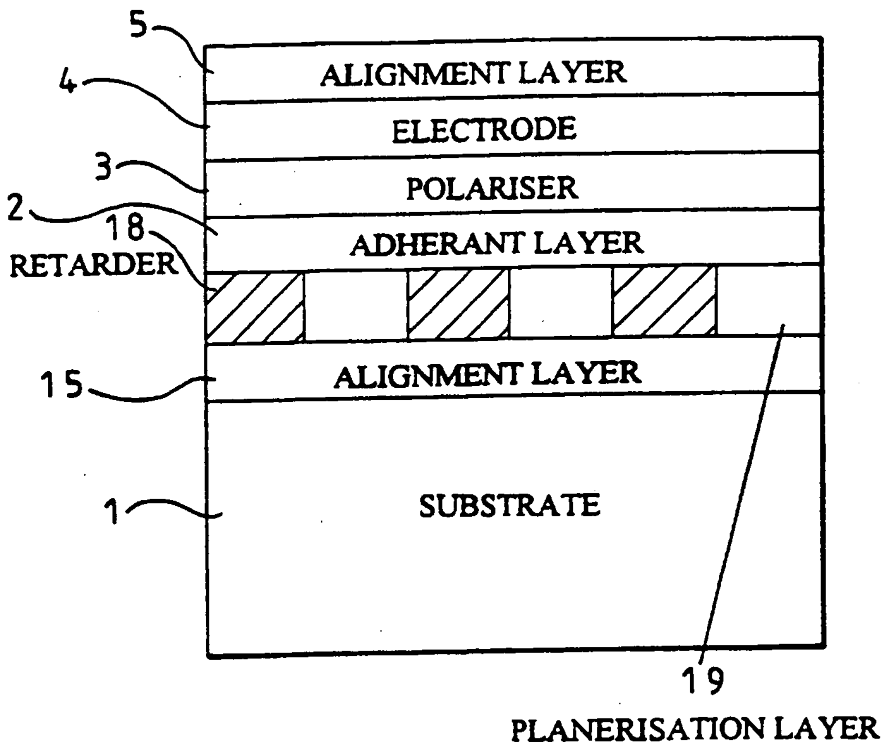

5
4
3
2
18
RETARDER
15
1
ALIGNMENT LAYER
ELECTRODE
POLARISER
ADHERANT LAYER
ALIGNMENT LAYER
SUBSTRATE
19
PLANERISATION LAYER

FIG 10

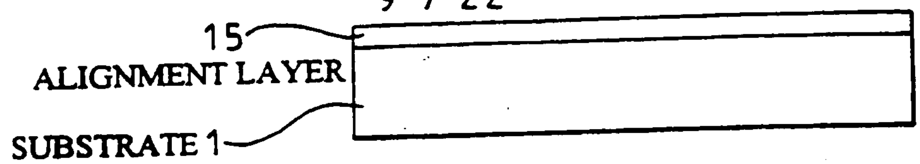


FIG 11a

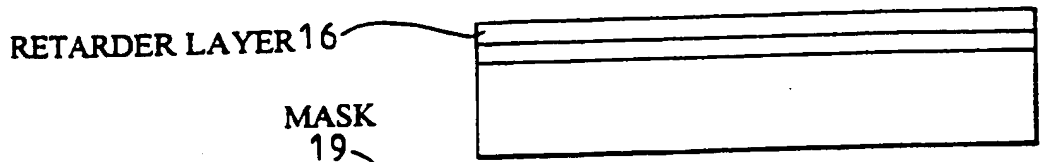


FIG 11b

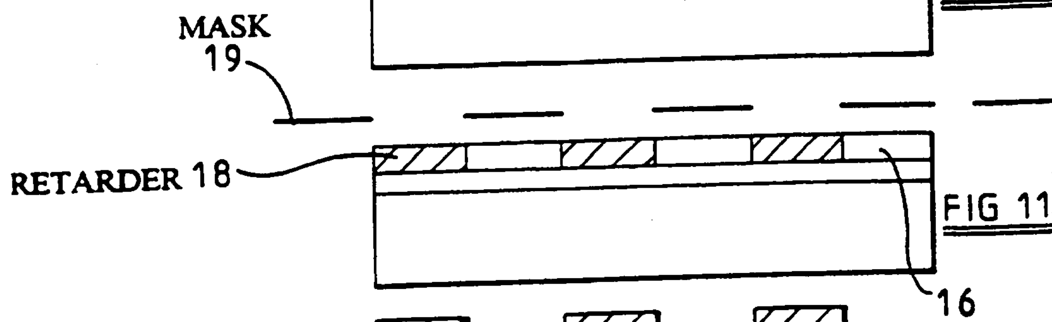


FIG 11c

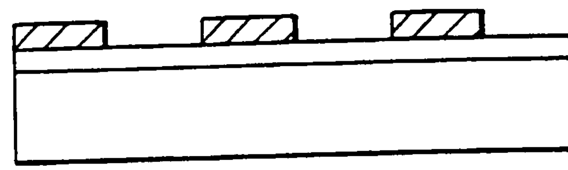


FIG 11d

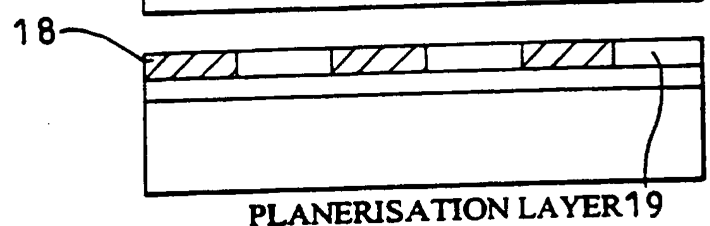


FIG 11e

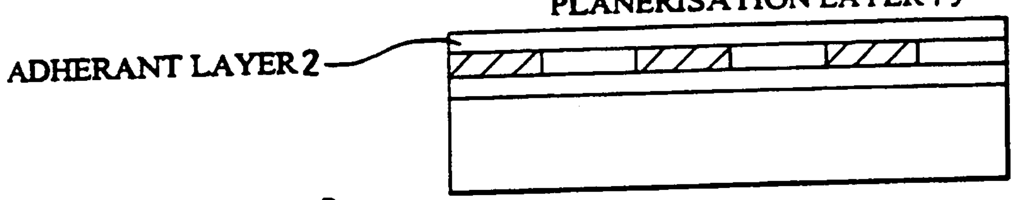


FIG 11f

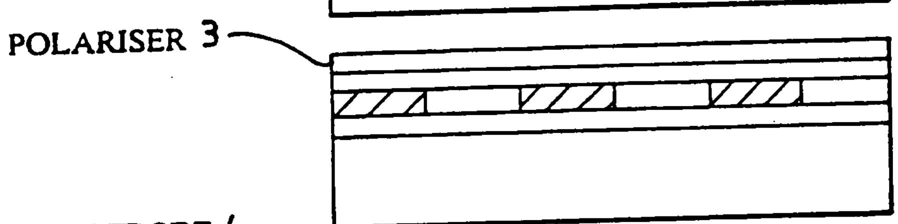


FIG 11g

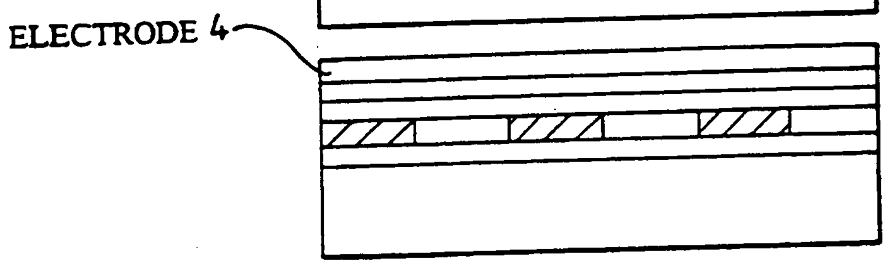


FIG 11h

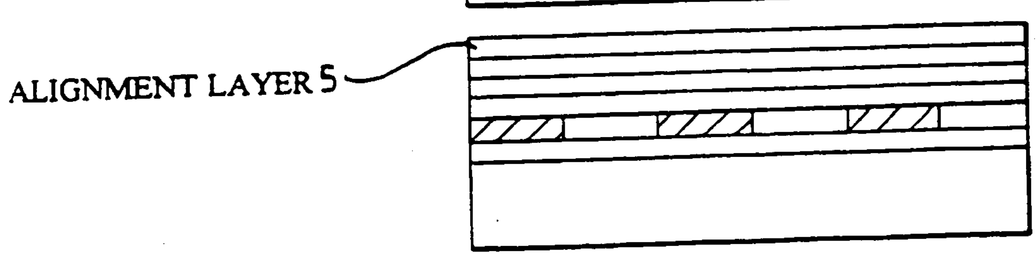


FIG 11i

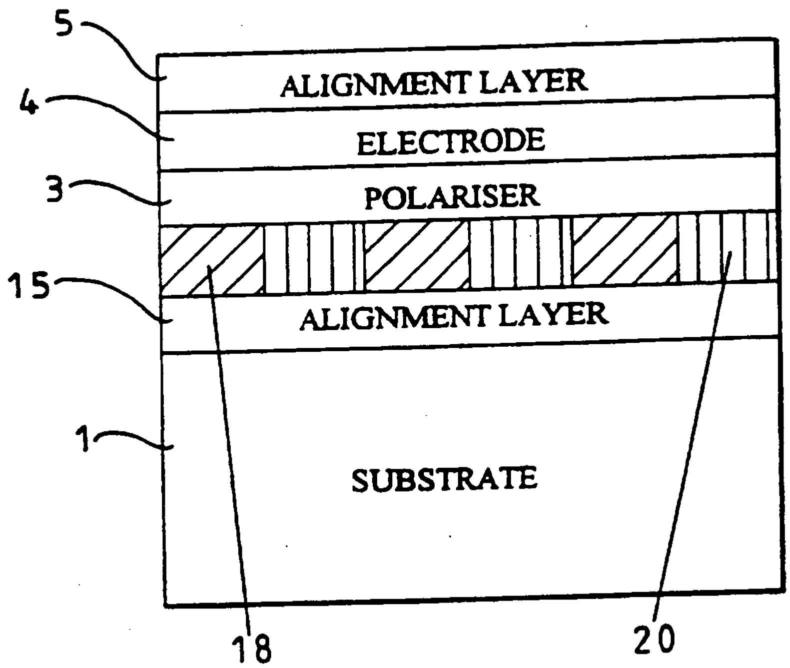

5
ALIGNMENT LAYER
4
ELECTRODE
3
POLARISER
15
ALIGNMENT LAYER
1
SUBSTRATE
18
20

FIG 12

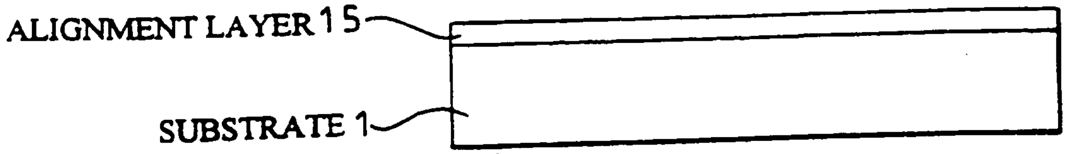


FIG 13a

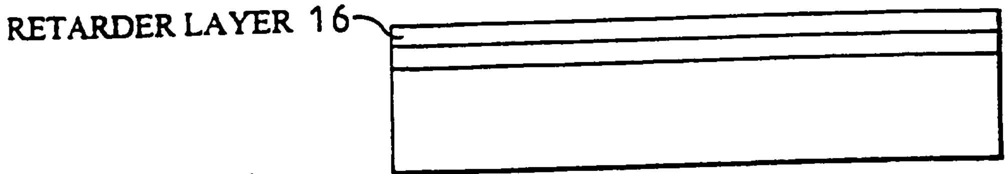


FIG 13b

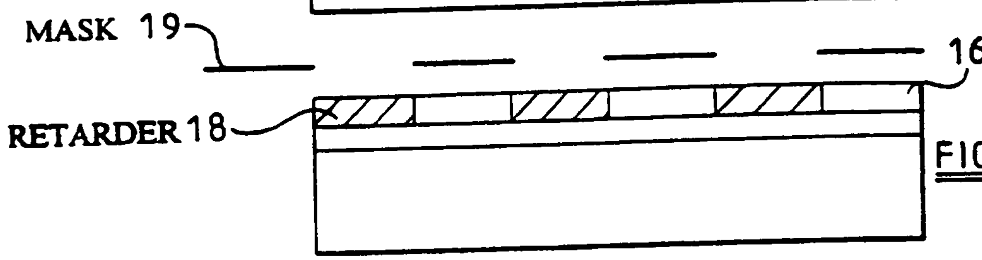


FIG 13c

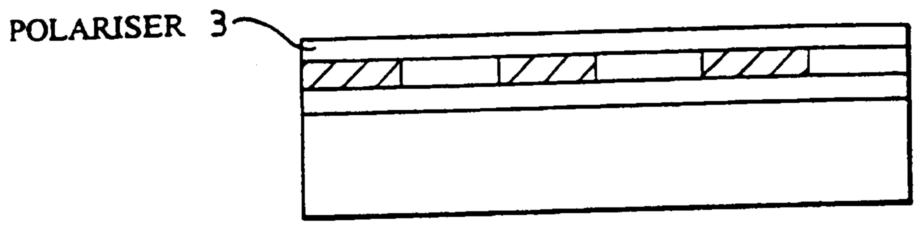


FIG 13d

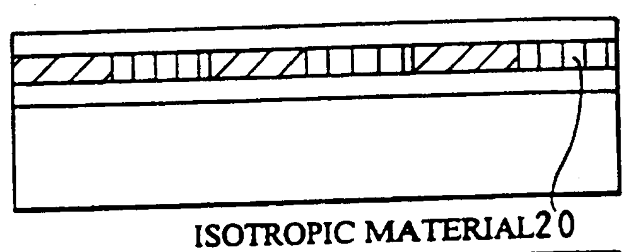


FIG 13e

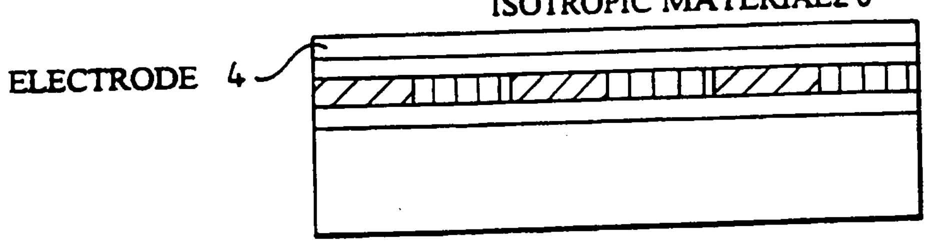


FIG 13f

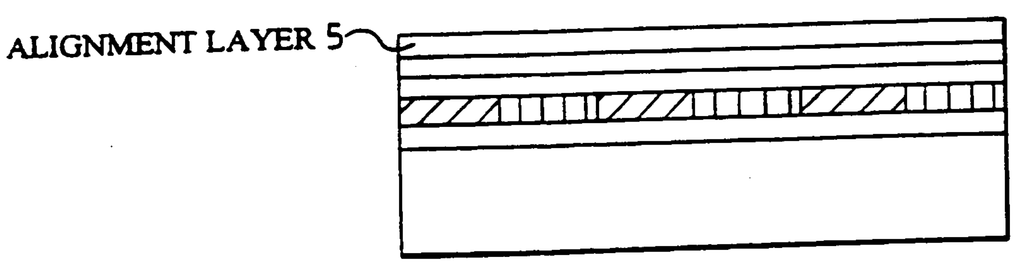
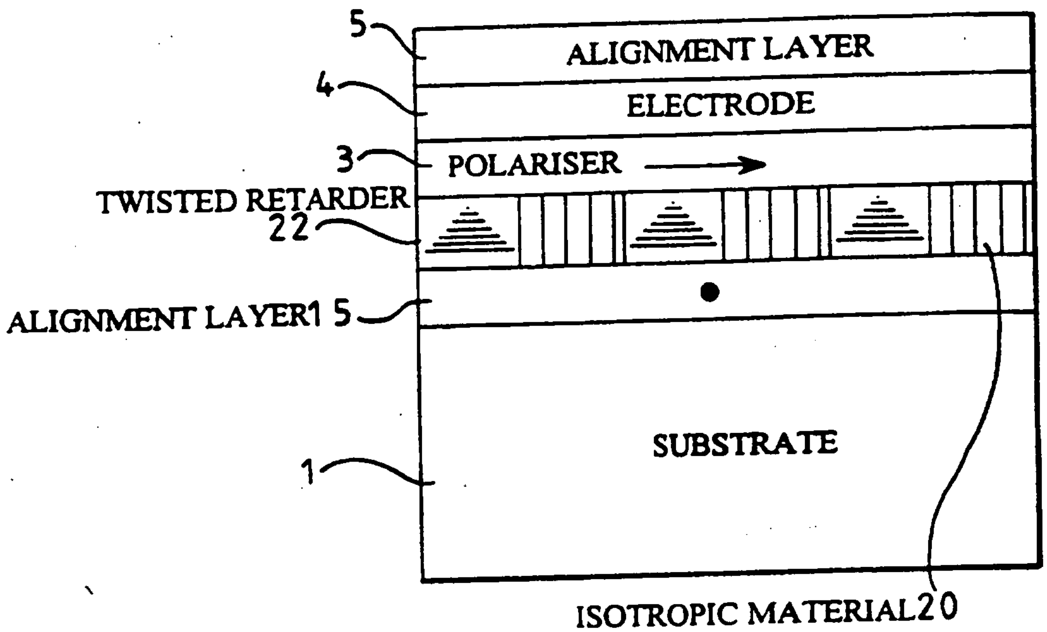


FIG 13g


5
ALIGNMENT LAYER
4
ELECTRODE
3
POLARISER
TWISTED RETARDER
22
ALIGNMENT LAYER15
SUBSTRATE
1
ISOTROPIC MATERIAL20

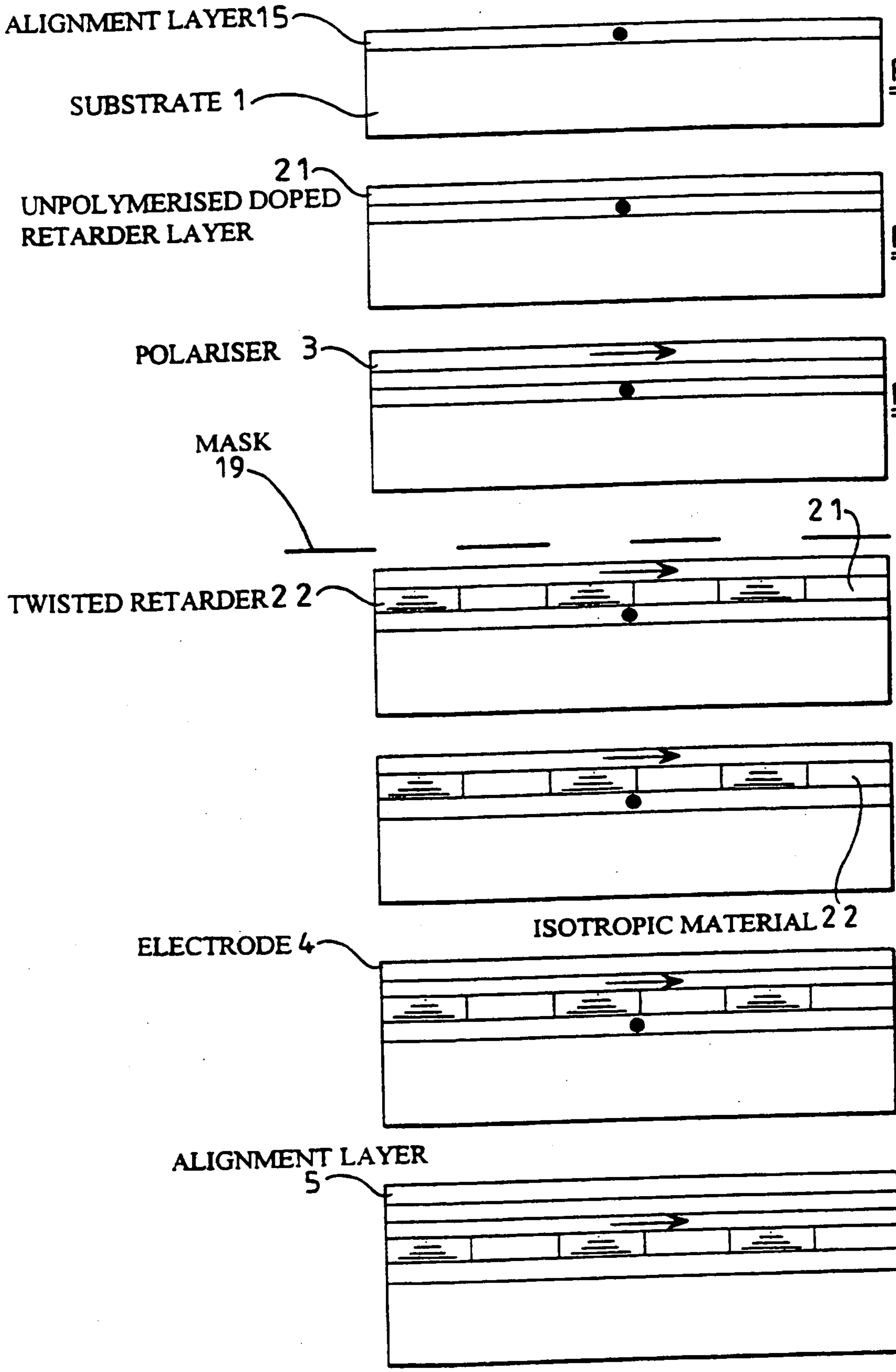


FIG 15a

FIG 15b

FIG 15c

FIG 15d

FIG 15e

FIG 15f

FIG 15g

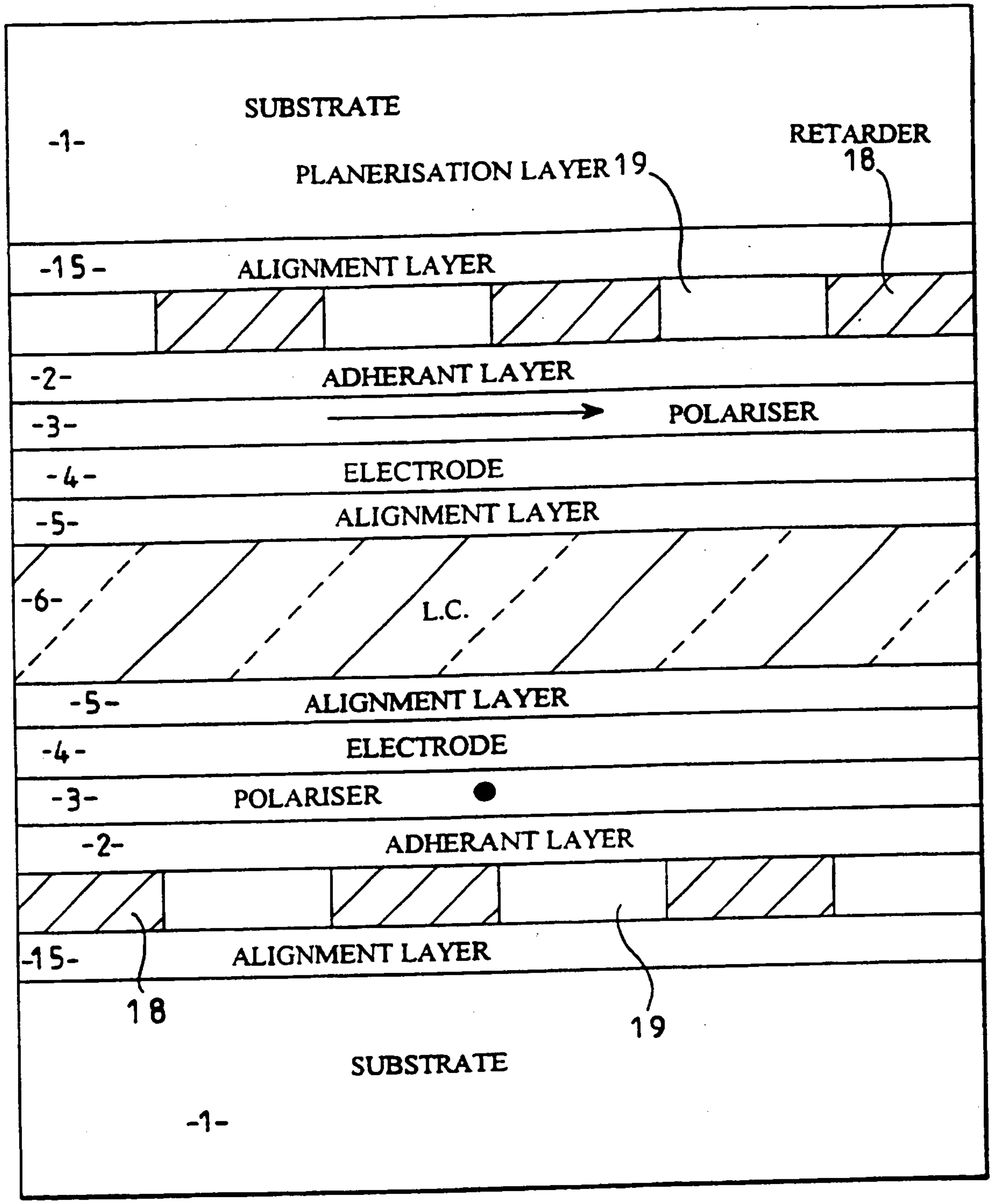

SUBSTRATE
-1-
RETARDER
18
PLANERISATION LAYER 19
-15-
ALIGNMENT LAYER
-2-
ADHERANT LAYER
-3-
POLARISER
-4-
ELECTRODE
-5-
ALIGNMENT LAYER
-6-
L.C.
-5-
ALIGNMENT LAYER
-4-
ELECTRODE
-3-
POLARISER
-2-
ADHERANT LAYER
-15-
ALIGNMENT LAYER
18
19
SUBSTRATE
-1-

FIG 16

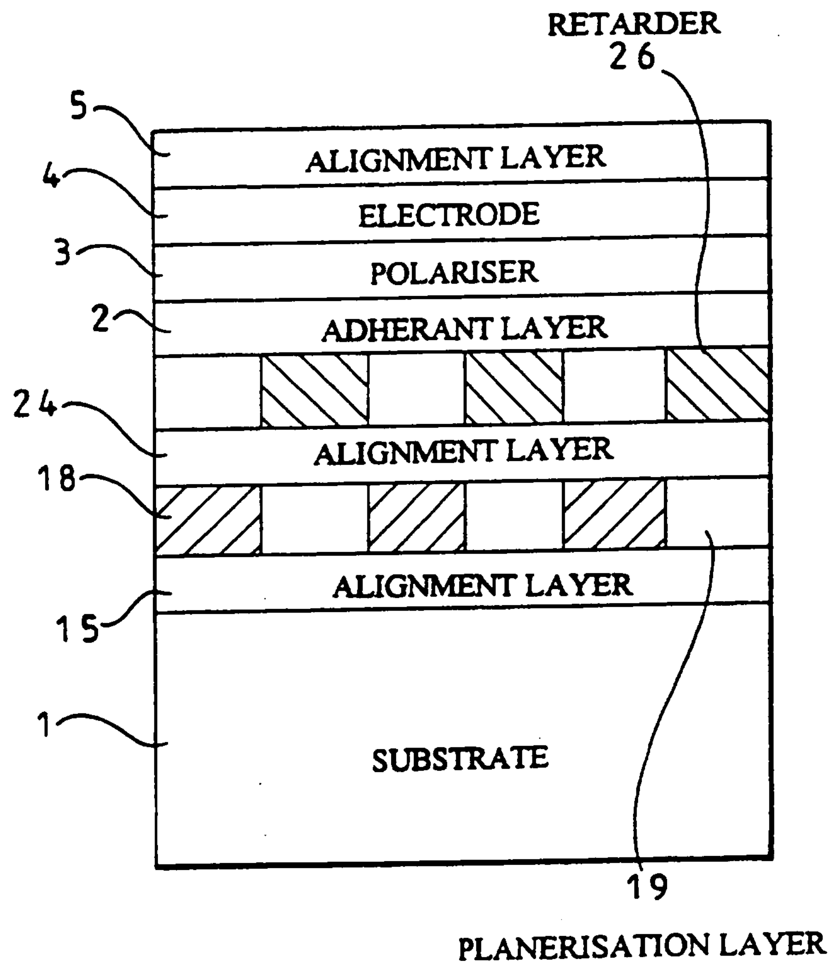
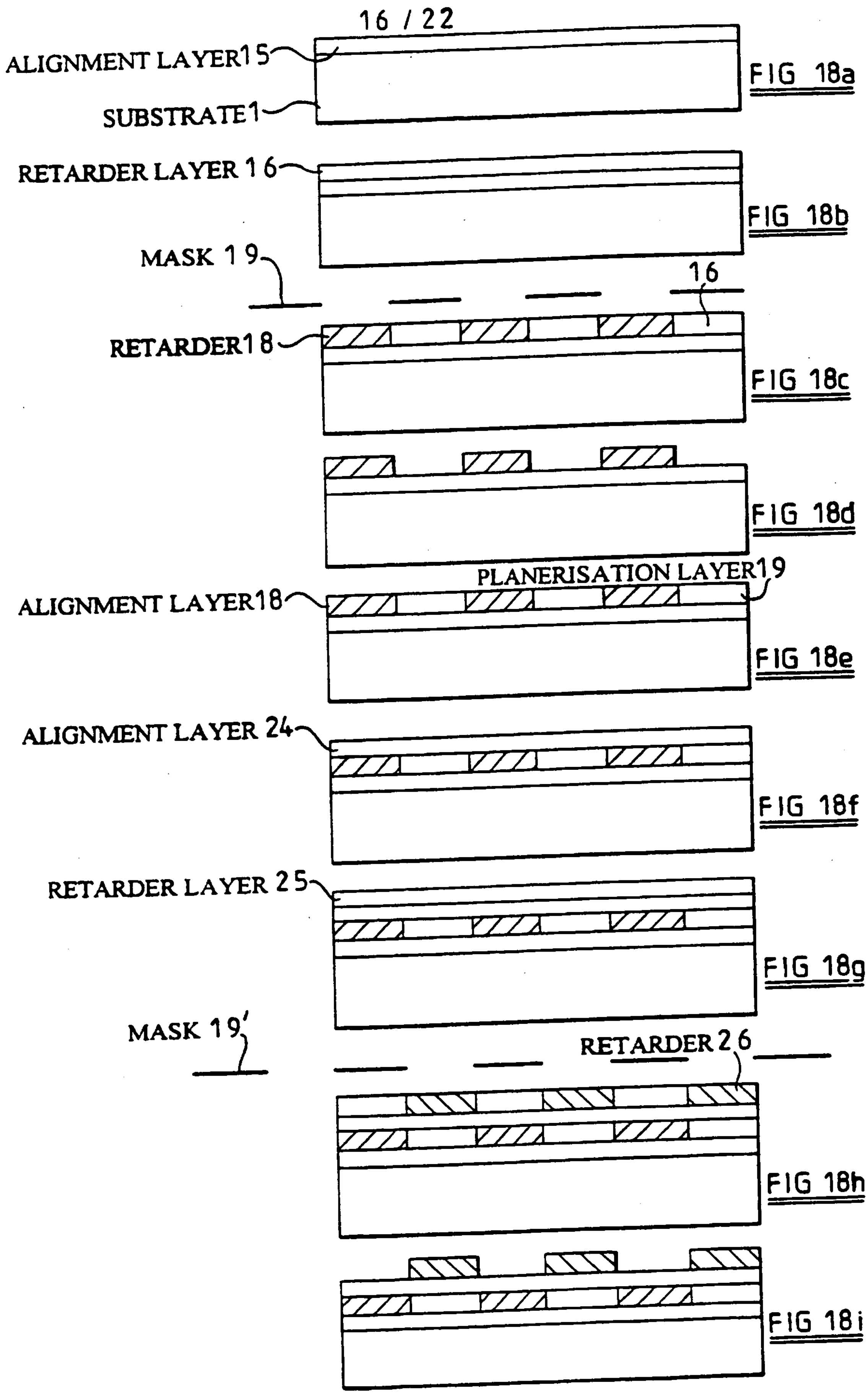

RETARDER
26
5
ALIGNMENT LAYER
4
ELECTRODE
3
POLARISER
2
ADHERANT LAYER
24
ALIGNMENT LAYER
18
ALIGNMENT LAYER
15
1
SUBSTRATE
19
PLANERISATION LAYER

FIG 17


16 / 22
ALIGNMENT LAYER 15
SUBSTRATE 1
FIG 18a
RETARDER LAYER 16
FIG 18b
MASK 19
16
RETARDER 18
FIG 18c
FIG 18d
PLANERISATION LAYER 19
ALIGNMENT LAYER 18
FIG 18e
ALIGNMENT LAYER 24
FIG 18f
RETARDER LAYER 25
FIG 18g
MASK 19'
RETARDER 26
FIG 18h
FIG 18i

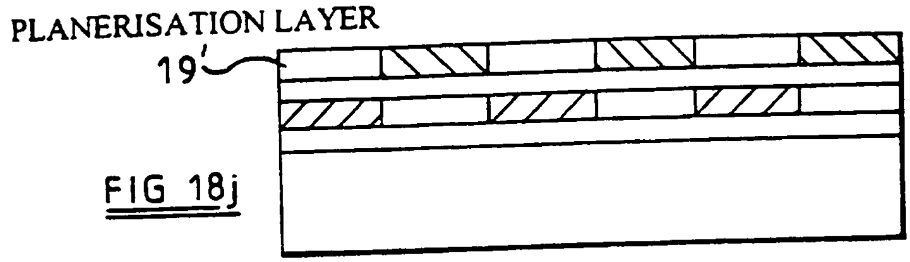


FIG 18j

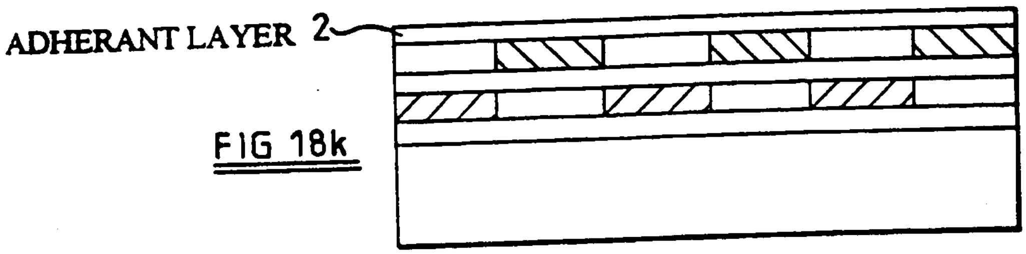


FIG 18k

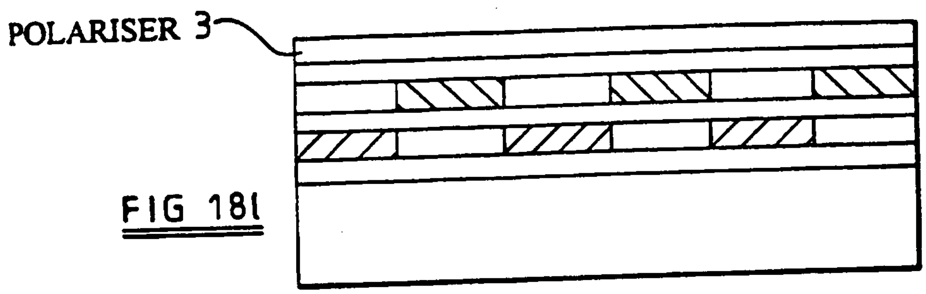


FIG 18l

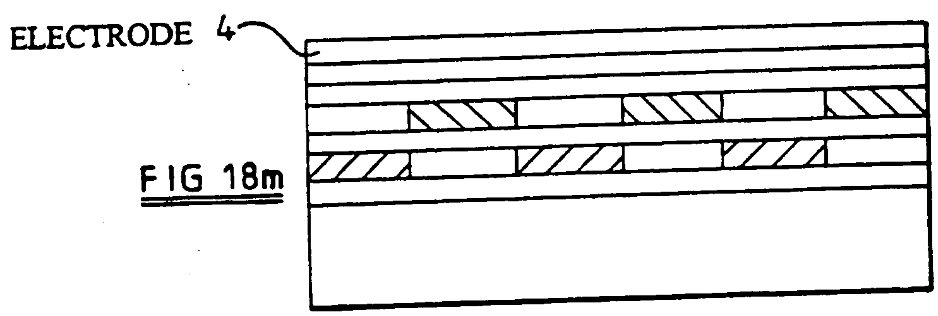


FIG 18m

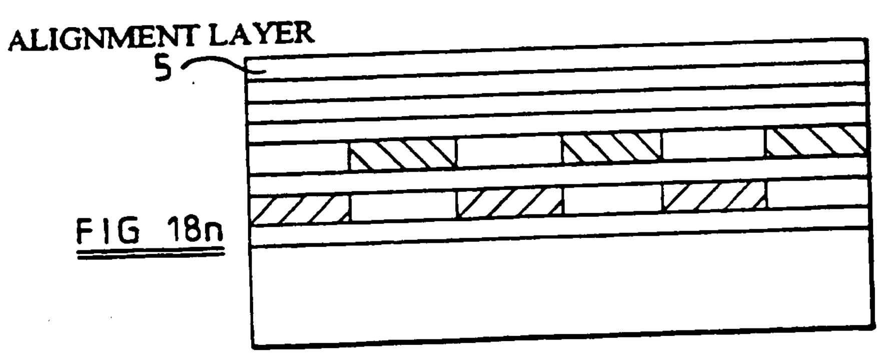


FIG 18n

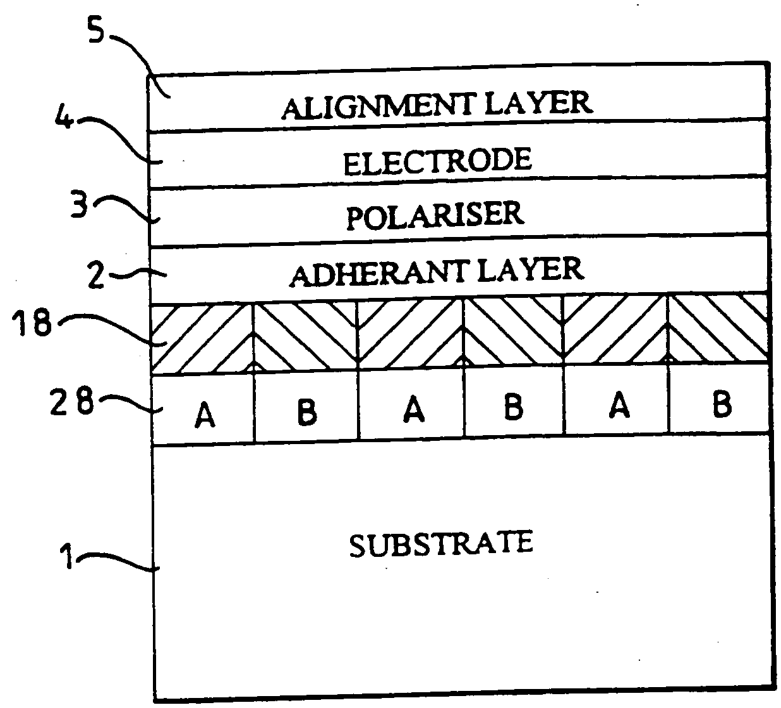


FIG 19a

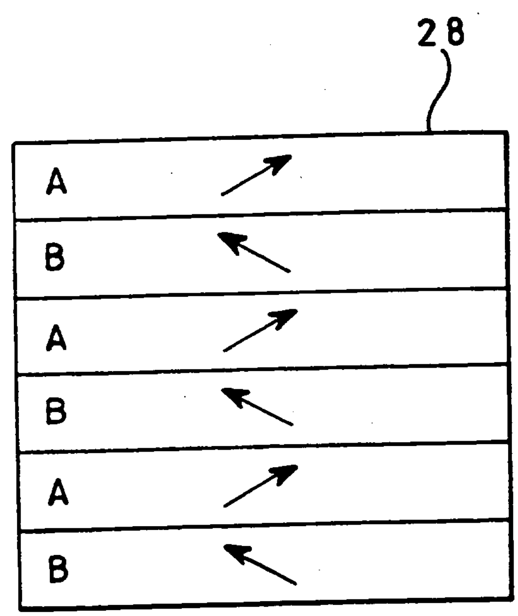
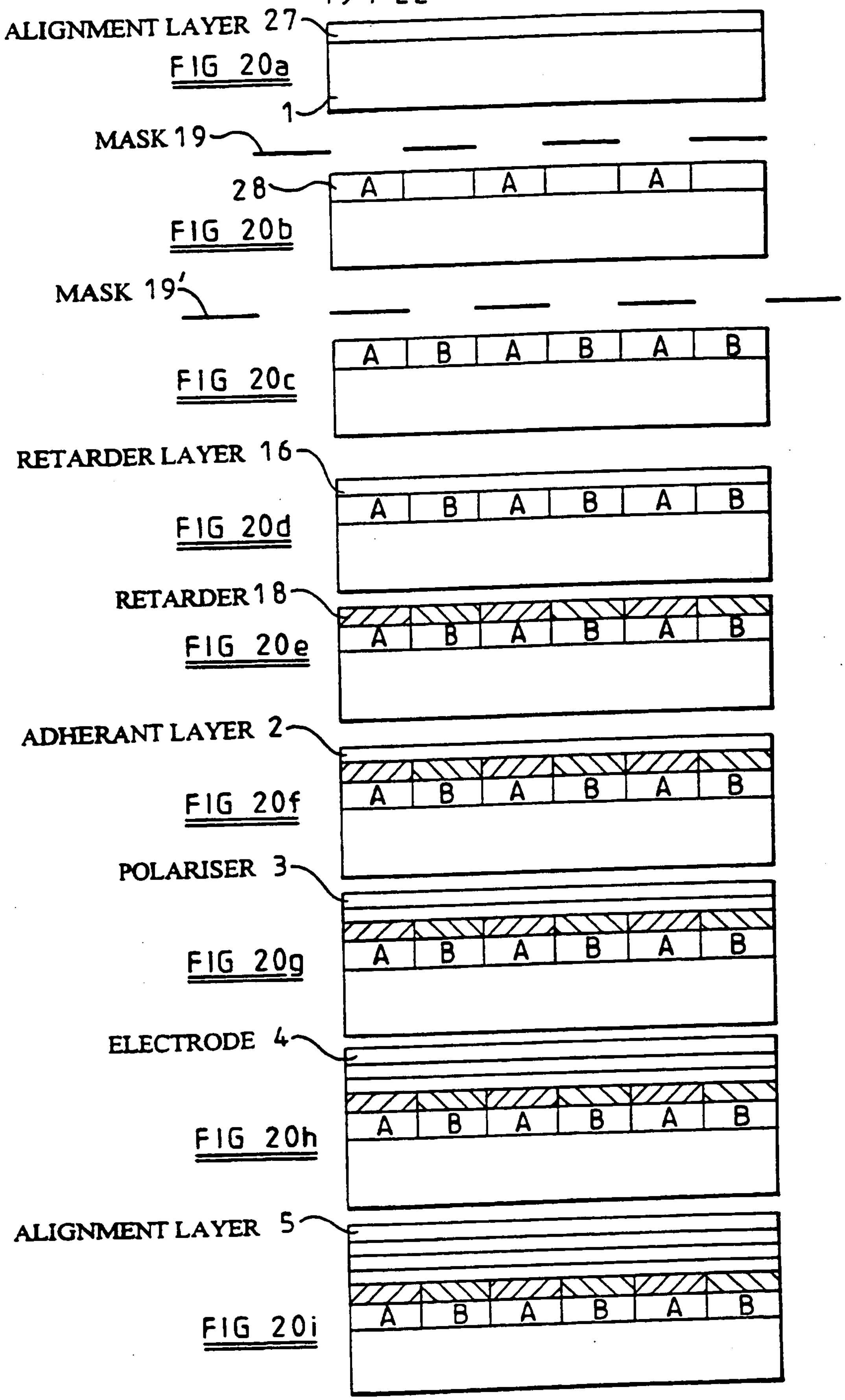


FIG 19b


ALIGNMENT LAYER 27
FIG 20a
1
MASK 19
28
A
FIG 20b
MASK 19'
A B A B A B
FIG 20c
RETARDER LAYER 16
FIG 20d
RETARDER 18
FIG 20e
ADHERANT LAYER 2
FIG 20f
POLARISER 3
FIG 20g
ELECTRODE 4
FIG 20h
ALIGNMENT LAYER 5
FIG 20i

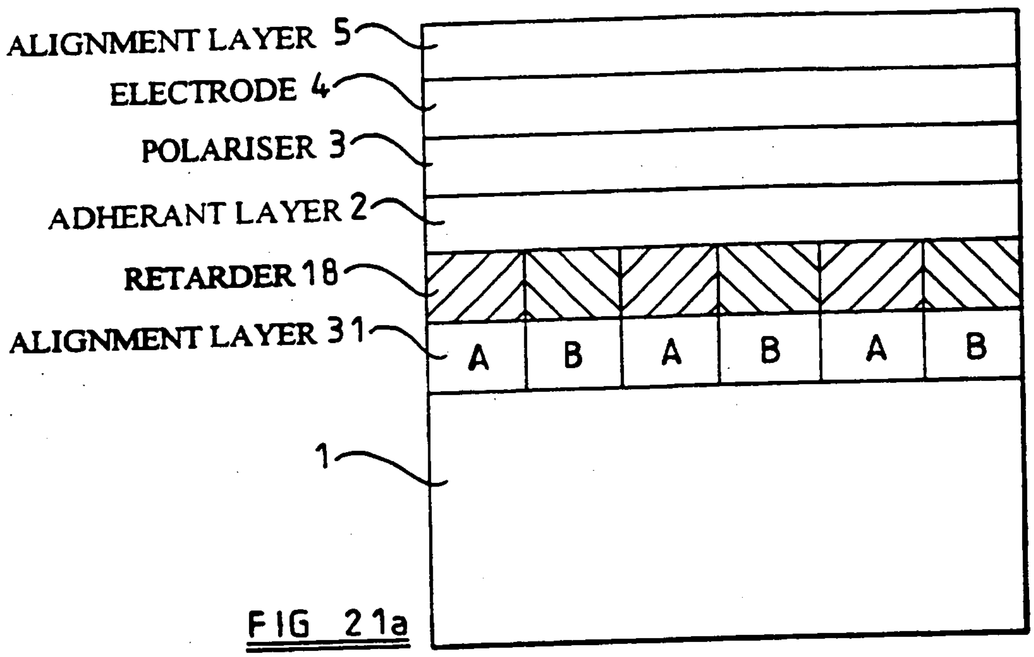


FIG 21a

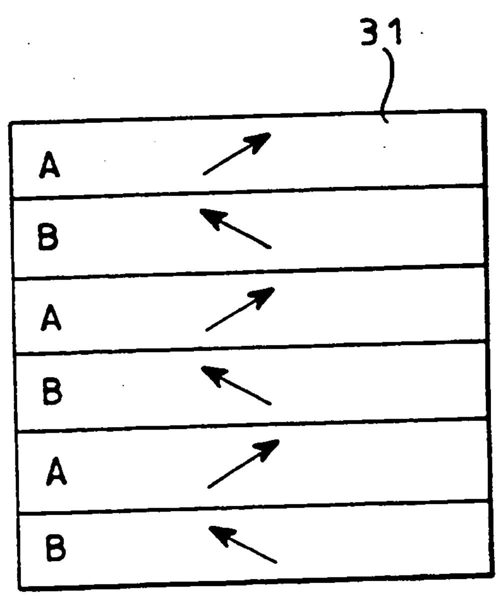


FIG 21b

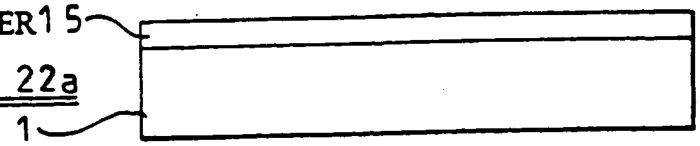


FIG 22a

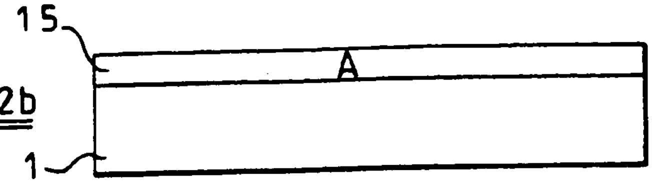


FIG 22b

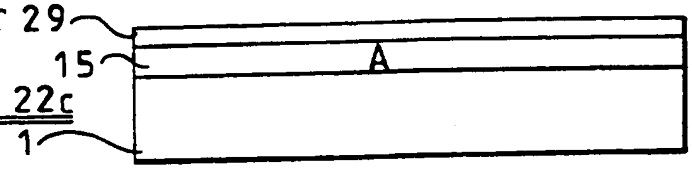


FIG 22c

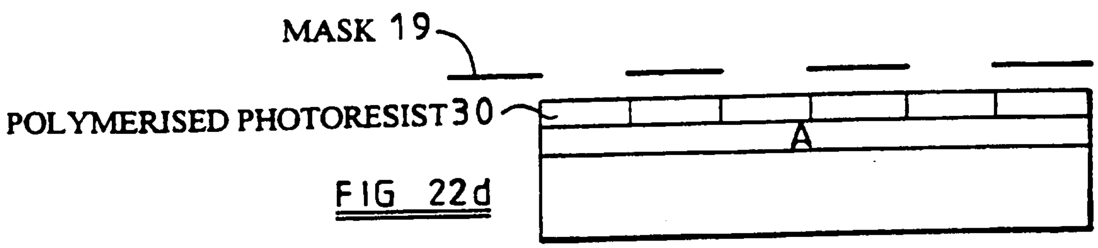


FIG 22d

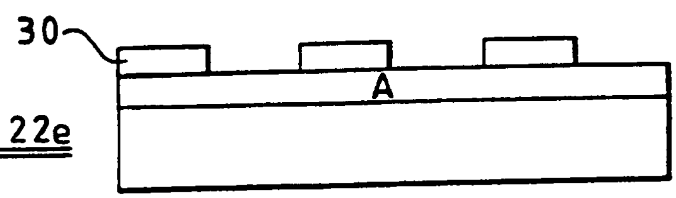


FIG 22e

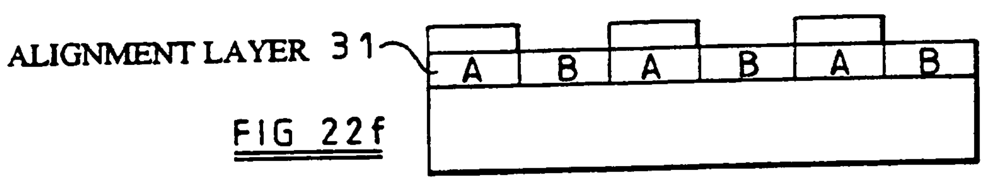


FIG 22f

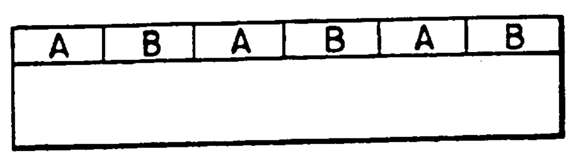


FIG 22g

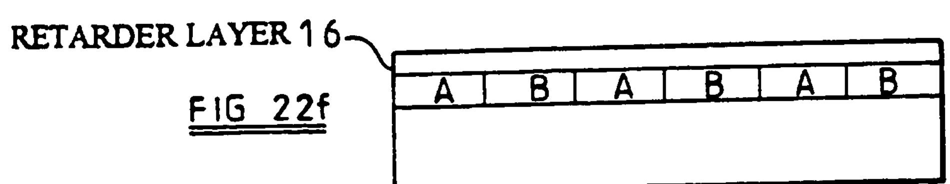


FIG 22f

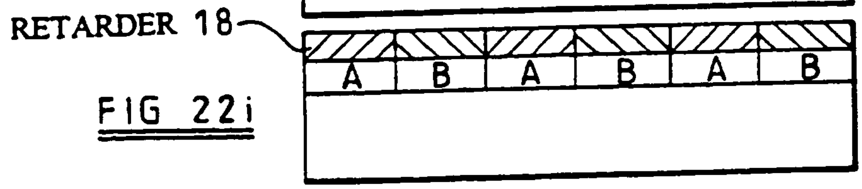
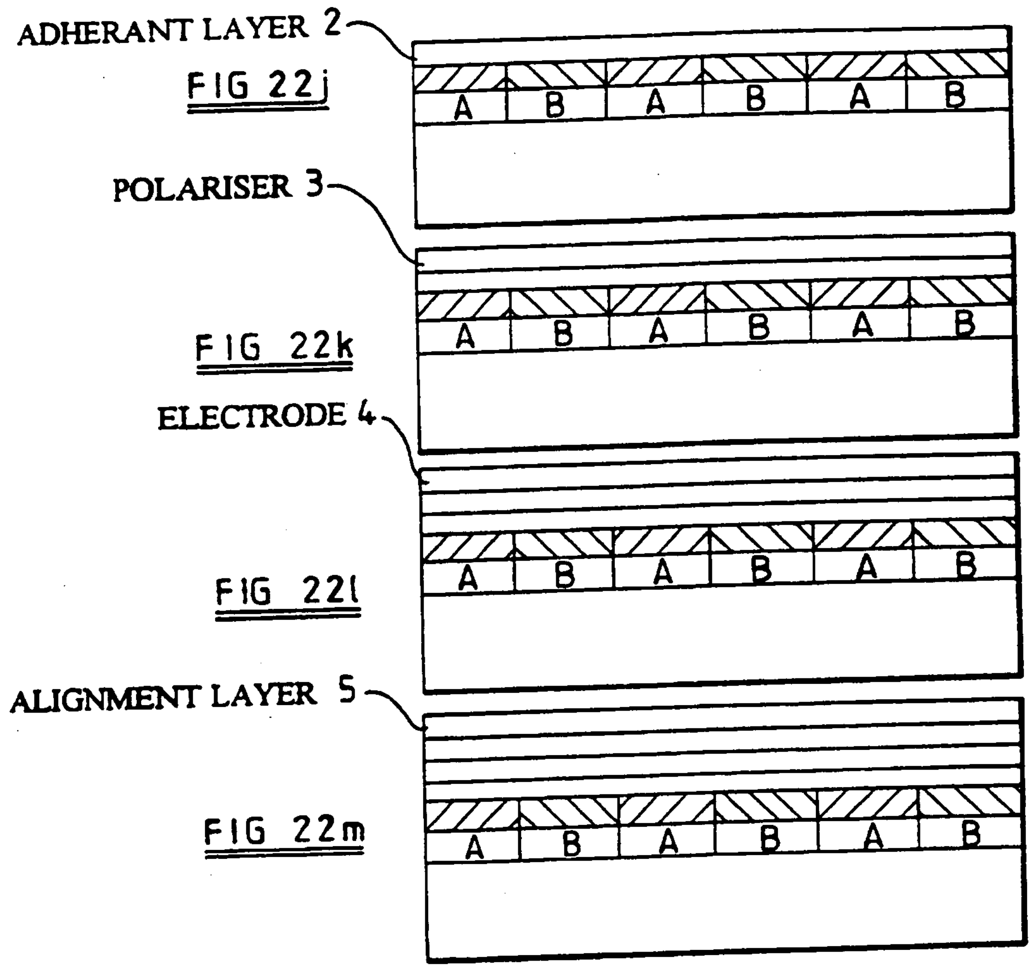


FIG 22i


ADHERANT LAYER 2
FIG 22j
A
B
A
B
A
B
POLARISER 3
FIG 22k
A
B
A
B
A
B
ELECTRODE 4
FIG 22l
A
B
A
B
A
B
ALIGNMENT LAYER 5
FIG 22m
A
B
A
B
A
B

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METHOD OF MAKING A SPATIAL LIGHT MODULATOR, METHOD OF MAKING A CELL WALL FOR SUCH A MODULATOR, SPATIAL LIGHT MODULATOR, AND CELL WALL FOR SUCH A SPATIAL LIGHT MODULATOR.

The present invention relates to a method of making a cell wall of a liquid crystal spatial light modulator and to a cell wall made by such a method. The invention also relates to a method of making a spatial light modulator and to a spatial light modulator made by such a method.

US 5 264 964 discloses a stereoscopic display which makes use of a pixellated polariser i.e. a polariser having regions of different polarisation directions. In particular, there are two sets of regions with one set of regions having a polarisation direction orthogonal to that of the other set. One set is associated with image portions of a right eye view whereas the other set is associated with image portions of a left eye view. However, the polariser is spaced by a significant distance from the image to be viewed and the resulting parallax results in a very limited freedom of movement for the observer to perceive a three dimensional (3D) image correctly. If the observer moves outside the viewing range, undesirable visual artefacts occur, such as pseudoscopic viewing in which the left eye of the observer sees some or all of the right view and vice versa.

JP 63-158525A discloses a flat liquid crystal stereoscopic device having internal polarising films comprising iodine absorbed on a stretched polyvinyl alcohol (PVA) film. However, a disadvantage of such iodine-

doped films is that the aligned polyiodide structure providing the dichroic ability is readily destroyed by the high temperatures employed in the fabrication of liquid crystal devices (LCDs), which temperatures are typically of the order of 180°C. Dichroic dye-based systems have a smaller tendency to lose their alignment on heating but, like iodine, are unsuitable for use inside an LCD because they are readily soluble in liquid crystal materials. Thus, the iodine would not remain localised in the polariser in the structures disclosed in this patent specification but would instead contaminate the liquid crystal material. Such structures are therefore not suitable for use as internal polarisers within LCDs.

EP 0 397 263 discloses a method of incorporating a dichroic dye within the polymer network of a liquid crystalline polymer (LCP). However, such LCP networks are unable to provide sufficient alignment of the dichroic dye in order to provide simultaneously good transmission and high contrast ratio of the minimum specification for polarisers for use in thin film transistor (TFT) LCDs. For such applications, a contrast ratio (ratio of transmission of light polarised in the direction of the polariser to transmission of orthogonally polarised light) of greater than 100:1 and transmission (of light polarised in the direction of the polariser) of greater than 80% are required. This is because dichroic dye molecules, even when perfectly dichroic, do not accurately adopt the intrinsic alignment of the host liquid crystal polymer. Further, LCP materials have a limited degree of alignment known as the "order parameter". The small variation in the dye orientation reduces transmission and it is not possible to obtain high transmission without poor extinction of the orthogonal polarisation.

US 5 049 427 discloses a polariser derived from oriented dichroic stretched polymer films typically containing conjugated double bonds such as those containing polyacetylene. The polariser itself is very thin and is bonded to a transparent polymer substrate, such as cellulose tri-acetate (CTA) with a polyurethane based adhesive. The optical properties of such a polariser become slightly diminished after spending a thousand hours at 100°C, which conditions may occur when such a polariser is used as an external polariser of an LCD in a video projector. We are not aware of any published data for polariser material endurance at a temperature greater than 100°C.

Methods of making patterned optical waveplates are known. For instance, "Molecular architectures in thin plastic films by in-situ photopolymerisation of reactive liquid crystals", Phillips, SID 95 Digest discloses a technique based on selective photopolymerisation of reactive liquid crystals whereas "Surface induced parallel alignment of liquid crystals by linearly polymerised photopolymers" Schadt et al, Japanese Journal of Applied Physics, volume 31, 1992, page 2155 discloses a technique based on the photopolymerisation of liquid crystal alignment layers including non-contact alignment of liquid crystals obtained by cross-linking polyvinylmethoxycinnamate using polarised light. EP 0 689 084 discloses the use of reactive mesogen layers as optical elements and alignment surfaces.

According to a first aspect of the invention, there is provided a method of making a cell wall of a liquid crystal spatial light modulator, comprising: forming a polariser made of a polymer comprising conjugated double bonds above a substrate; and forming a layer above the polariser relative to the substrate.

The polymer may contain polyacetalene.

The layer may comprise a first alignment layer. The first alignment layer may comprise polyimide. Following completion of the cell wall including at least one elevated temperature processing step, the polariser may have a contrast ratio of at least 10:1 at at least one operating wavelength of the spatial light modulator. The contrast ratio may be 100:1. The at least one operating wavelength may comprise a waveband having an upper limit greater than or equal to 600 nanometres and a lower limit less than or equal to 510 nanometres. The upper limit may be greater than or equal to 700 nanometres and the lower limit may be less than or equal to 400 nanometres.

Following completion of the cell wall including at least one elevated temperature processing step, the polariser may have a transmission of polarised light of at least 50%. The transmission may be at least 80%.

The first alignment layer may be cured at substantially 180°C or up to substantially 180°C for substantially two hours or up to substantially two hours. The first alignment layer may be cured at substantially 120°C or up to substantially 120°C for substantially one hour or up to substantially one hour.

The polariser may be formed on an adherent layer. The adherent layer may comprise polyimide. After forming the polariser, the adherent layer may be cured at substantially 140°C or up to substantially 140°C for substantially thirty minutes or up to substantially thirty minutes.

In one embodiment, the adherent layer is formed on the substrate. In another embodiment, the adherent layer is formed on a colour filter arrangement carried by the substrate. In a further embodiment, the adherent layer is formed on an electrode carried by the substrate.

The electrode may be formed on the polariser.

The layer may comprise an electrode.

At least one patterned retarder may be formed between the substrate and the first alignment layer before forming the first alignment layer.

The or each patterned retarder may be formed by: forming a second alignment layer; forming a retarder layer on the second alignment layer; and selectively removing part of the retarder layer.

The patterned retarder or one of the patterned retarders may be formed by: forming a second alignment layer; forming a retarder layer on the second alignment layer; curing part of the retarder layer by exposure to ultraviolet radiation; forming the polariser on the retarder layer; heating the retarder layer above its isotropic transition point; and exposing the retarder layer to ultraviolet radiation. The retarder layer may comprise a chiral retarder layer and the polariser may be formed on the retarder layer for which it acts as a further alignment layer. The absorbtion direction of the polariser may be substantially perpendicular to the alignment direction of the second alignment layer.

A plurality of patterned retarders may be formed with the alignment direction of the second alignment layer of each of the patterned retarders

being different from the alignment direction of the second alignment layer of each other of the patterned retarders.

The or each patterned retarder may be formed by: forming a layer of linearly photopolymerisable material; exposing first parts of the material layer to radiation of a first polarisation; and exposing second parts of the material layer to radiation of a second polarisation.

The or each patterned retarder may be formed by: forming a second alignment layer; rubbing the second alignment layer in a first alignment direction; forming on the second alignment layer a mask which reveals predetermined regions of the second alignment layer; rubbing the predetermined regions in a second alignment direction different from the first alignment direction through the mask; removing the mask; and forming a retarder layer on the second alignment layer.

According to a second aspect of the invention, there is provided a method of making a liquid crystal spatial light modulator, comprising making a first cell wall by a method according to a first aspect of the invention, spacing the first cell wall from a second cell wall to form a gap, and filling the gap with a liquid crystal material.

The second cell wall may be made by a method according to the first aspect of the invention.

The alignment directions of the first alignment layers of the first and second cell walls may be substantially orthogonal. The liquid crystal material may comprise a nematic liquid crystal and a chiral dopant.

According to a third aspect of the invention, there is provided a cell wall made by a method according to the first aspect of the invention.

According to a fourth aspect of the invention, there is provided a spatial light modulator made by a method according to the second aspect of the invention.

It is thus possible to provide a technique which allows internal polarisers, which may or may not be patterned or pixellated, to be formed inside LCDs. It has been unexpectedly found that internal polarising elements made of a polymer comprising conjugated double bonds can withstand the manufacturing conditions of such devices while retaining acceptable optical properties such as transmission and contrast ratio. In particular, the heat treatment used to form various layers, such as alignment layers and electrodes, during manufacture unexpectedly does not reduce to unacceptable levels the polariser performance. Further, such polarisers do not cause contamination of other parts of the devices, such as liquid crystal layers. The formation of cell walls may involve temperatures up to 200°C but it has been found that, with the present invention, internal polarisers may be incorporated compatibly with the high temperature stages of LCD fabrication, in particular curing of alignment layers and deposition of electrodes such as indium tin oxide (ITO) electrodes.

The polariser may be formed from the active layer only and does not require any substrate when it is formed as part of a cell wall of an LCD.

Thus, the present invention allows the incorporation of a polariser inside an LCD in a manner which is compatible with standard alignment layer

and other processing. Disposing the polariser between its substrate and the liquid crystal layer has the advantage that the substrate need not have or retain very low birefringence, as is necessary for external polarisers. Thus, the substrate may be made of lower quality glass or even cheap transparent plastics which exhibit substantial birefringence. Because the effects of such birefringence occur optically outside the LCD, they are not visible to observers, whose eyes are not sensitive to polarisation.

Further, the use of an internal polariser with or without a patterned retarder avoids problems of unwanted parallax. Spatial light modulators (SLMs) of this type are therefore suitable for use in 3D displays, for instance of the type disclosed in EP 0 721 132, the contents of which are incorporated herein by reference.

The invention will be further described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic cross-sectional diagram of an SLM constituting an embodiment of the invention;

Figure 2 is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 3 is a schematic cross-sectional view of an SLM constituting an embodiment of the invention;

Figure 4 is schematic cross sectional view of an SLM of the type shown in Figure 1 including a TFT array;

Figure 5 is a schematic cross-sectional view showing a cell wall from which an alignment layer has optionally been omitted;

Figure 6 is a schematic cross-sectional view of a cell wall from which a transparent conducting electrode has optionally been omitted;

Figure 7 is a schematic cross-sectional view of a cell wall including a heat stabilisation layer;

Figure 8 is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 9, which comprises Figure 9a to 9h, illustrates a method of making the cell wall of Figure 8;

Figure 10 is schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 11, which comprises Figures 11a to 11i, illustrates a method of making the cell wall of Figure 10;

Figure 12 is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 13, which comprises Figures 13a to 13g, illustrates a method of making the cell wall of Figure 12;

Figure 14 is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 15, which comprises Figures 15a to 15g, illustrates a method of making the cell wall of Figure 14;

Figure 16 is a schematic cross-sectional view of an SLM constituting an embodiment of the invention;

Figure 17 is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 18, which comprises Figures 18a to 18n, illustrates a method of making the cell wall of Figure 17;

Figure 19a is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 19b is a diagrammatic plan view of one of the layers of the cell wall of Figure 19a;

Figure 20, which comprises Figures 20a to 20i, illustrates a method of making the cell wall illustrated in Figures 19a and 19b;

Figure 21a is a schematic cross-sectional view of a cell wall constituting an embodiment of the invention;

Figure 21b is a diagrammatic plan view of one of the layers of the cell wall of Figure 21a; and

Figure 22, which comprises Figures 22a to 22m, illustrates a method of making the cell wall illustrated in Figures 21a and 21b.

Like reference numerals refer to like parts throughout the drawings.

The liquid crystal SLM shown in Figure 1 comprises first and second cell walls with the liquid crystal disposed therebetween. The first cell wall comprises a substrate 1, for instance of polished soda-lime glass, which is coated with a transparent electrode 4, for instance of ITO, having resistivity of less than 20 ohms per square. An adherent layer 2 is formed on the electrode 1 and may comprise an epoxy based system. For instance, the adherent layer may be formed of the commercially available epoxy adhesive Epotek 301 diluted in butoxyethanol in the ratio 1:3 by weight which is spun in an open bowl spin coater at 4,000rpm for 30 seconds.

A polariser 3 is formed on the adherent layer 2 and comprises a stretched polyacetalene/polyvinyl alcohol copolymer, for instance of the type disclosed in US 5 049 427. After applying the polariser 3 to the adherent layer 2, the adherent layer is cured at 20°C for six hours.

A polyimide liquid crystal alignment layer 5 is formed on the polariser 3. For example, the polyimide may comprise a polyimide sold by Du Pont under the designation PI 2555 dissolved 1:20 in a solvent comprising a mixture of N-methyl-2-pyrrolidone and 1-methoxypropan-2-ol as sold by Du Pont under the designation T 9039, which is spun in an open bowl spin coater at 4,000rpm for 30 seconds. The polyimide alignment layer 5 is then cured by heating at 170°C for two hours. The alignment layer 5 is then rubbed with a soft cloth to impose a preferred direction and pre-tilt on the alignment layer.

The second cell wall comprising a substrate 11, a transparent electrode 10, an adherent layer 9, a polariser 8 and an alignment layer 7 is made in the same way as the first cell wall. Plastic spacer beads, for instance of 10 micrometer diameter, are sprayed onto the alignment layer 5 and the liquid crystal cell is assembled with the spacer beads between the alignment layers 5 and 7 and with the alignment directions of the alignment layers 5 and 7 substantially perpendicular to each other. The interior of the cell between the alignment layers 5 and 7 is sealed, for instance using an ultraviolet curable adhesive, and filled with a mixture 6 comprising a nematic liquid crystal containing a chiral dopant so as to produce a 90 degree twisted nematic cell.

In the SLM shown in Figure 1, the electrodes 4 and 10 are spaced further from the liquid crystal layer 6 than is usual because of the interposition of the adherent layers 2 and 9 and the polarisers 3 and 8. The drive voltages for the SLM are therefore adjusted to compensate for the dielectric effect of these additional layers.

It was found that the processing steps to form the first and second cell walls did not unacceptably degrade the performance of the polarisers 3 and 8. In particular, despite the use of elevated temperatures for prolonged periods to cure the alignment layers 5 and 7, the polarisers 3 and 8 retained satisfactory transmission and contrast ratio for commercial use of the SLM.

The method of making the first and second cell walls may be modified in various ways. For instance, the alignment layers 5 and 7 may be made of a polyimide such as that sold by Du Pont under the designation AM 4276, cured at 120°C for one hour. The use of such lower temperature

curing alignment layers further reduces the degradation of the polarisers 3 and 8.

The adherent layers 2 and 9 may be made of other materials, such as commercially available polyurethane based adhesives. An example of such an adhesive is Dymax light weld 401 which may be applied to the electrodes 4 and 10 by spinning in an open bowl spin coater at 5,000rpm for thirty seconds. The polarisers 3 and 8 are applied to the adherent layers 2 and 9, which are then cured by exposure to ultraviolet light, for instance having a wavelength of 365 nanometres and a power of 50 milliwatts per square centimetre for 60 seconds.

The adherent layers 2 and 9 may also be made of a polyimide, for instance comprising PI 2555 dissolved 1:20 in T 9039 spun in an open bowl spin coater at 5,000rpm for 10 seconds. After the polarisers 3 and 8 have been formed, the polyimide adherent layers 2 and 9 are cured at 140°C for thirty minutes. An advantage of the use of such a polyimide is that it is known to be compatible with LCD fabrication and operation.

The processing conditions during making of the first and second cell walls must be such that degradation of the performance of the polarisers 3 and 8 is sufficiently small to yield devices of acceptable operation. In particular, the polarisers should preferably retain substantially achromatic transmission of at least 80% and achromatic contrast ratios of at least 100:1. The choice of materials and fabrication techniques for those layers formed after the polarisers 3 and 8 must therefore be such as not to degrade the polariser performance beyond acceptable limits for the specific application. This affects the choice of material and fabrication technique of the alignment layers 5 and 7 and any other layers (as

described hereinafter) formed after the polarisers. In the case of the alignment layers, for instance, the cure temperature and duration should be such as not to cause undue damage to the polarisers. Curing should preferably take place less than 180°C for two hours and more preferably less than 150°C for two hours.

The substrates 1 and 11 may be made of low alkali glass, such as Corning 7059, typically with a thickness of 1.1 mm. An advantage of being able to form the polarisers 3 and 8 between the substrates 1 and 11 is that any birefringence occurring in the substrates does not substantially affect the performance of the SLM. This allows much greater freedom of choice of materials for the substrates 1 and 11. For instance, the substrates may be made of plastics including polyethylene terephthalate, polyethersulfone, polymethylmethacrylate, polyesters or polycarbonates. Materials which may have residual or stress induced birefringence may therefore be used whereas such materials would be unsuitable for use in SLMs of conventional type having external polarisers.

The adherent layers 2 and 9 may be made from any suitable adhesive or tacking material fulfilling the requirements of high transparency, achromaticity, thermal stability and preferably thermal expansion similar to that of the polarisers 3 and 8. Examples of suitable materials for the adherent layers are organic adhesives such as epoxy resins, acrylic polymers or those based on polyurethane derivatives. These may be applied to the underlying surface by any suitable technique such as printing, rolling, casting or spin coating to achieve a uniform thin layer. After application of the polarisers 3 and 8, such adhesives may be cured by thermal, free-radical or photochemical means. In addition to

commonly available adhesives, it may be advantageous to use materials which are already used for other purposes in the fabrication of LCDs because their compatibility with such devices is already established. Suitable materials are those which are tacky on application and so provide some adhesive function, such as polyimides, polyamides and polyvinyl alcohol solution.

The polarisers 3 and 8 may be made from any suitable stretched polymer which contains conjugated double bonds and which is thermally stable. After completion of fabrication of the SLM, the polarisers preferably have a contrast ratio of at least 100:1, preferably over a range of bandwidths of 510 to 600 nanometres and more preferably over a range of 400 to 700 nanometres. The polarisers preferably have a transmission of at least 50% and more preferably at least 80% for linearly polarised light. The polarisers preferably retain or exceed these properties after exposure to at least 100°C for at least thirty minutes and more preferably to at least 180°C for at least two hours. Further, the polariser material should preferably be resistant to common process solvents such as isopropyl alcohol, acetone, n-methyl pyrrolidinone, sodium hydroxide and toluene. The polarisers 3 and 8 are preferably of uniform thickness so as not to introduce thickness variations in the liquid crystal layer 6. The polarisers are preferably thin so as to facilitate the deposition of stable transparent conducting electrodes (where these are formed on or above the polarisers), preferably less than 30 micrometres thick and more preferably less than 10 micrometres thick.

The transparent conducting electrodes 4 and 10 are preferably made from ITO applied by any process which is compatible with the temperature requirements of the polarisers when the electrodes are

formed on or above the polarisers. For instance, deposition of such electrodes is preferably such that the polarisers are subjected to temperatures of less than 200°C. For example, low temperature electron beam or sputtering processes may be used to apply the electrodes 4 and 10. The electrodes preferably have a transmission of at least 90% and a resistivity of less than 100 ohms per square. Either or both electrodes 4 and 10 may be etched to provide a plurality of segmented electrodes as required, for instance to define picture elements (pixels) of the SLM.

The cell wall shown in Figure 2 differs from those shown in Figure 1 in that the electrode 4 is formed between the alignment layer 5 and the polariser 3 rather than between the adherent layer 2 and the substrate 1. The layers 2, 3 and 5 are formed as described with reference to Figure 1 whereas the electrode 4 is formed by sputtering onto the polariser 3, for instance by vaporising an ITO target in a low pressure argon/oxygen atmosphere. Either or both cell walls may be formed in this way. As described hereinbefore, where the electrode 4 is formed on or above the polariser 3, the processes for forming the electrode must be such as not to degrade the performance of the polariser 3 beyond acceptable limits. However, an advantage of the arrangement shown in Figure 2 compared with that shown in Figure 1 is that there are fewer dielectric layers between the electrode 4 and the liquid crystal 6. Accordingly, conventional drive voltages may be used without having to take account of additional dielectric layers.

Figure 3 illustrates an SLM including a colour filter arrangement. A black mask 1b for obscuring regions of the SLM which are required not to be visible is formed on the substrate 1 and a planarisation layer 1c is formed above the black mask 1b to provide a plane surface for further

processing. Colour filters 1a, such as red, green and blue pixel colour filters, in an appropriate arrangement are formed on the planarisation layer 1c and a further planarisation layer 1d is formed on the colour filters 1a. The colour filter arrangement may, for instance, be formed as disclosed in "progress in colour filters for LCDs", Toppan Printing Company, SID 94 Digest page 103.

The first and second cell walls are then formed as described hereinbefore. However, Figure 3 illustrates an additional barrier layer 4a which may be formed on the electrode 4 so as to help prevent short circuits across the liquid crystal layer 6.

The SLM shown in Figure 4 has a first cell wall of the type shown in Figure 2 and a second wall which differs from those shown in Figures 1 to 3 in that the internal polariser 8 is omitted and an external polariser 13 is provided. Further, a thin film transistor (TFT) array 12 is formed between the substrate 11 and the alignment layer 7 and also provides the electrodes in place of the electrode 10. The TFT array 12 may be of a known type for providing an active LCD. This arrangement has the advantage of not requiring the introduction of extra processing steps to the TFT array 12, which extra steps might otherwise reduce the yield. Further, because the polariser 13 is disposed outside the cell, it may be of a conventional type such as iodine doped stretched polyvinyl alcohol. The second cell wall shown in Figure 4 may be used with other first cell wall arrangements, for instance as illustrated in Figures 1 and 3 or in the embodiments described hereinafter.

The cell wall shown in Figure 5 differs from those described hereinbefore in that the alignment layer 5 is omitted. Such an arrangement may be

used with electrooptic effects which do not require specific alignment layers, such as the axially symmetric mode. Alternatively, the polariser 3 may provide an aligning effect, for instance when it comprises polyacetylene which may be used to act as a low pre-tilt alignment surface. Such an arrangement may be advantageous if the opposite alignment layer 7 provides a high pre-tilt.

The cell wall illustrated in Figure 6 differs from that illustrated in Figure 5 in that the electrode 4 is omitted. In this arrangement, the electrode function is provided by the intrinsic conductivity of the material, such as polyacetylene, forming the polariser 3. The conductivity may be enhanced, for example by doping with arsenic pentafluoride.

As shown in Figure 7, a sealant layer 14 may be formed on the polariser 3 so as to help in protecting the polariser during heat treatments in the fabrication of the cell wall. The layer 14 may also be used to improve the optical performance, particularly at short wavelengths.

The alignment layers 5 and 7 may be of any material suitable for providing the desired alignment of the liquid crystal 6. For instance, rubbed polyimide as described hereinbefore or silicon oxide may be used depending on the requirement of the liquid crystal effect for pre-tilt, homeotropic or planar alignment. Because the alignment layers are in direct contact with the liquid crystal layer, suitable materials are selected to prevent contamination, particularly conductive contamination of the liquid crystal. Such contamination is particularly disadvantageous in TFT displays where the resulting conductive leakage can produce undesirable flicker. As described hereinbefore, the alignment layers 5 and 7 may have different alignment directions so as to impose a twist on the liquid

crystal director. such arrangements may be used to provide twisted nematic (TN) or super twisted nematic (STN) devices. However, other alignments and types of devices may be formed using the techniques disclosed herein. Also, the separation of the first and second cell walls may be selected as appropriate for the type of device and is typically between 1 and 10 micrometres. Also, the plastic bead spacers for defining and maintaining the separation of the alignment layers may be replaced by any other suitable means, such interpixel polymer walls.

Figure 8 illustrates a cell wall of an SLM which is particularly useful for 3D displays of the type disclosed in EP 0 721 132. The cell wall incorporates a patterned optical retarder which is therefore internal to the substrates. The patterned retarder may be made of any material which is suitable for its location inside the cell and which is capable of withstanding the processes during manufacture. The arrangement shown in Figure 8 comprises an alignment layer 15 disposed on the substrate 1 and a birefringent material forming the retarder 18 with the retarder axis being fixed by the alignment layer.

Figure 9 illustrates manufacture of the cell wall of Figure 8. In Figure 9a, the alignment layer 15 is applied to the substrate 1. The alignment layer 15 may be of the same type as described hereinbefore and may be formed in the same way. Figure 9b shows the application of an optical retarder layer 16 whose alignment direction is determined by the alignment layer 15. The retarder layer 16 comprises any suitable birefringent material which may be aligned and subsequently fixed in a predetermined direction. A suitable material comprises a liquid crystal polymer or a reactive mesogen. An example of a suitable reactive

mesogen is that known as RM 257 available from Merck, UK having a high birefringence which allows the use of relatively thin layers.

As shown in Figure 9c, regions of the retarder layer 16 are exposed to ultraviolet radiation through a mask 19 so as to be photopolymerised. As shown in Figure 9d, the unpolymerised regions are then removed, for instance by an etching process, to reveal the desired patterned optical retarder arrangement. Figures 9e to 9h then show the applications of the adherent layer 2, the polariser 3, the electrode 4, and the alignment layer 5, which processes are as described hereinbefore.

The cell wall shown in Figure 10 differs from that shown in Figure 8 in that the patterned retarder is planarised by means of a planarisation layer 19 before the adherent layer 2 is applied. The planarisation layer 19 fills the gaps left by the removed unpolymerised retarder material and the additional step during manufacture of the cell wall is illustrated in Figure 11e. The other parts of Figure 11 are as described with reference to Figure 9. The material of the planarisation layer is preferably isotropic, transparent and substantially similar in thickness to the retarders 18. Suitable materials include acrylic and epoxy resins.

The cell wall shown in Figure 12 and the method of making it illustrated in Figure 13 differ from those illustrated in Figures 8 and 9 in that, after the selective photopolymerisation shown in Figure 9c, the unpolymerised retarder material 16 is not removed. Further, the adherent layer 2 is omitted and, instead, the polariser 3 is formed on the retarder layer 16. The unpolymerised retarder material is still tacky so that the polariser adheres to it. The workpiece is then heated to a temperature above the isotropic transition point of the unpolymerised retarder material, which is

cured in an isotropic state by exposure to long wavelength ultraviolet radiation. This results in a layer having regions of isotropic material 20 and birefringent material 18 as illustrated in Figure 13e. It is also possible to add an extra amount of unpolymerised material after the selective polymerisation. Such a layer covers the previously polymerised regions as well as the unpolymerised regions and so attaches the polariser more firmly. The extra material is polymerised in the isotropic state as described hereinbefore and has no optical effect on the previously selectively polymerised regions. Otherwise, the method of making the cell wall is as described hereinbefore with reference to Figure 9.

The cell wall and method of making it illustrated in Figures 14 and 15 differ from those illustrated in Figures 12 and 13 in that a chiral dopant is added to the reactive mesogen mixture before application as the retarder layer 21. The chiral dopant introduces a continuous rotation of the retarder direction on passing through the layer so as to provide a guiding twisted retarder. The polariser 3 is applied to the unpolymerised doped retarder layer 21 before selective photopolymerisation is performed as shown in Figure 15d. The absorbtion direction of the polariser 3 is substantially perpendicular to the alignment direction of the alignment layer 15 as illustrated by the arrow and dot, respectively, in Figures 15a to 15g. The polariser 3 aligns the top surface of the doped retarder 21 so as to ensure that a desired twist angle is achieved without requiring the very precise layer thickness control which would otherwise be necessary. The manufacturing steps illustrated in Figure 15e, f and g are the same as those described with reference to Figures 13e, f and g, respectively.

Figure 16 illustrates an SLM in which the first and second cell walls are of the type illustrated in Figure 14. Thus, both cell walls include patterned optical retarders and the cell walls are arranged such that the polarising directions of the polarisers 3 are orthogonal. Such an SLM is particularly suitable for use in a 3D display of the type disclosed in EP 0 721 132.

Figures 17 and 18 illustrate a cell wall and a method of making it which differ from those illustrated in Figures 10 and 11, respectively, in that a further patterned retarder 26 is formed within the cell. After the planarisation layer 19 is applied as shown in Figure 18e, another alignment layer 24, for instance of the same type as the alignment layer 15, is applied, for instance in the same way. The alignment layer 24 is applied with an alignment direction different from that of the alignment layer 15. A further retarder layer 25, for instance of the same type as the retarder layer 16 is formed, for instance in the same way, on the alignment layer 24. The layer 25 is selectively exposed to ultraviolet radiation through a mask 19' so that regions 26 forming the further patterned optical retarder are photopolymerised. The unpolymerised regions are then removed as illustrated in Figure 18i and a further planarisation layer 19' is formed. The subsequent steps of forming the layers 2, 3, 4 and 5 are then as described hereinbefore.

By using this technique, it is possible to provide alternate areas of retarders aligned in different directions. For instance, the retarders 18 and 26 may be aligned to act as $+\lambda/4$ and $-\lambda/4$ waveplates or as $+\lambda/2$ and $-\lambda/2$ waveplates. SLMs using cell walls of this type are suitable for use in 3D displays, for instance as disclosed in EP 0 721 132.

By repeating the process steps illustrated in Figures 18b to 18e, multiple stacked layers of patterned retarders may be fabricated.

Figure 19a and 19b show another cell wall and Figure 20 illustrates another method of making it, both of which differ from those shown in Figures 10 and 11, respectively, in that the standard alignment layer 15 is replaced by a layer of linearly photopolymerisable material 27, for instance of the type described in "Surface Induced Parallel Alignment of Liquid Crystals by Linearly Polymerised Photopolymers, Schadt et al, Japanese Journal of Applied Physics, volume 31 (1992), page 2155 and EP 0 689 084. The layer is selectively exposed to radiation of a first linear polarisation through a mask 19 as shown in Figure 20b to form exposed regions A. The unexposed regions B are then exposed via a mask 19' to radiation having a different linear polarisation. Thus, alternate regions of the alignment layer 28 provide different alignment directions, for example different by 45 or 90 degrees. Figure 19b illustrates this in a plan view of the layer 28. The retarder layer 16 is then applied as shown in Figure 20d as described hereinbefore. However, the retarder adopts the alternate directions imposed by the underlying part of the alignment layer 28 and so does not require selective photopolymerisation. Instead, the retarder layer 16 may be cured by exposure to a uniform ultraviolet source. The retarder regions may thus be arranged to act as $+\lambda/4$ and $-\lambda/4$ waveplates or as $+\lambda/2$ and $-\lambda/2$ waveplates and an SLM using such cell walls is suitable for use in 3D displays, for instance as disclosed in EP 0 721 132.

Figures 21a and 21b show another cell wall and Figure 22 illustrates another method of making it, both of which differ from those shown in Figures 10 and 11, in that the alignment layer 15 is rubbed twice. It is

first rubbed in the direction A. Photoresist material 29 is applied and selectively polymerised through a mask 19 as shown in Figure 22d. This may be done using known photolithographic techniques. The unpolymerised material is removed leaving the polymerised photoresist material 30 and regions of the underlying alignment layer 15 exposed. The assembly is then rubbed in a second direction B to produce an alignment layer with a spatially varying alignment direction 31. The polymerised photoresist material is then removed. The retarder layer 16 is then applied as shown in Figure 22h as described hereinbefore. However, the retarder adopts the alternate directions imposed by the underlying part of the alignment layer 31 and so does not require selective photopolymerisation. Instead the retarder layer 16 may be cured by exposure to a uniform ultraviolet source. The retarder regions may thus be arranged, for example, to act as $+\lambda/4$ and $-\lambda/4$ waveplates or as $+\lambda/2$ and $-\lambda/2$ waveplates and an SLM using such cell walls is suitable for use in 3D displays, for instance as disclosed in EP 0 721 132".

CLAIMS

1. A method of making a cell wall of a liquid crystal spatial light modulator, comprising: forming a polariser made of a polymer comprising conjugated double bonds above a substrate; and forming a layer above the polariser relative to the substrate.

2. A method as claimed in Claim 1, in which the polymer contains polyacetylene.

3. A method as claimed in Claim 1 or 2, in which the layer comprises a first alignment layer.

4. A method as claimed in Claim 3, in which the first alignment layer comprises polyimide.

5. A method as claimed in any one of the preceding claims, in which, following completion of the cell wall including at least one elevated temperature processing step, the polariser has a contrast ratio of at least 10:1 at at least one operating wavelength of the spatial light modulator.

6. A method as claimed in Claim 5, in which the contrast ratio is at least 100:1.

7. A method as claimed in Claim 5 or 6, in which the at least one operating wavelength comprises a waveband having an upper limit greater than or equal to 600 nanometres and a lower limit less than or equal to 510 nanometres.

8. A method as claimed in Claim 7, in which the upper limit is greater than or equal to 700 nanometres and the lower limit is less than or equal to 400 nanometres.

9. A method as claimed in any one of the preceding claims, in which, following completion of the cell wall including at least one elevated temperature processing step, the polariser has a transmission of polarised light of at least 50%.

10. A method as claimed in Claim 9, in which the transmission is at least 80%.

11. A method as claimed in Claim 3 or 4 or any one of Claims 5 to 10 when dependent on Claim 3 or 4, in which the first alignment layer is cured at substantially 180°C or up to substantially 180°C for two hours or up to substantially two hours.

12. A method as claimed in Claim 11, in which the first alignment layer is cured at substantially 120°C or up to substantially 120°C for one hour or up to substantially one hour.

13. A method as claimed in any one of the preceding claims, in which the polariser is formed on an adherent layer.

14. A method as claimed in Claim 13, in which the adherent layer comprises polyimide.

15. A method as claimed in Claim 14, in which, after forming the polariser, the adherent layer is cured at substantially 140°C or up to

substantially 140°C for substantially thirty minutes or up to substantially thirty minutes.

16. A method as claimed in any one of Claims 13 to 15, in which the adherent layer is formed on the substrate.

17. A method as claimed in any one of Claims 13 to 15, in which the adherent layer is formed on a colour filter arrangement carried by the substrate.

18. A method as claimed in any one of Claims 13 to 15, in which the adherent layer is formed on an electrode carried by the substrate.

19. A method as claimed in any one of Claims 1 to 17, in which an electrode is formed on the polariser.

20. A method as claimed in Claim 1 or 2, in which the layer comprises an electrode.

21. A method as claimed in Claim 3 or 4 or in any one of Claims 5 to 19 when dependent on Claim 3, in which at least one patterned retarder is formed between the substrate and the first alignment layer before forming the first alignment layer.

22. A method as claimed in Claim 21, in which the or each patterned retarder is formed by: forming a second alignment layer; forming a retarder layer on the second alignment layer; and selectively removing part of the retarder layer.

23. A method as claimed in Claim 21, in which the patterned retarder or one of the patterned retarders is formed by: forming a second alignment layer; forming a retarder layer on the second alignment layer; curing part of the retarder layer by exposure to ultraviolet radiation; forming the polariser on the retarder layer; heating the retarder layer above its isotropic transition point; and exposing the retarder layer to ultraviolet radiation.

24. A method as claimed in Claim 22, in which the retarder layer comprises a chiral retarder layer and the polariser is formed on the retarder layer for which it acts as a further alignment layer.

25. A method as claimed in Claim 24, in which the absorption direction of the polariser is substantially perpendicular to the alignment direction of the second alignment layer.

26. A method as claimed in any one of Claims 21 to 25, in which a plurality of patterned retarders is formed with the alignment direction of the second alignment layer of each of the patterned retarders being different from the alignment direction of the second alignment layer of each other of the patterned retarders.

27. A method as claimed in Claim 21, in which the or each patterned retarder is formed by: forming a layer of linearly photopolymerisable material; exposing first parts of the material layer to radiation of a first polarisation; and exposing second parts of the material layer to radiation of a second polarisation.

28. A method as claimed in Claim 21, in which the or each patterned retarder is formed by: forming a second alignment layer; rubbing the second alignment layer in a first alignment direction; forming on the second alignment layer a mask which reveals predetermined regions of the second alignment layer; rubbing the predetermined regions in a second alignment direction different from the first alignment direction through the mask; removing the mask; and forming a retarder layer on the second alignment layer.

29. A method of making a liquid crystal spatial light modulator, comprising making a first cell wall by a method as claimed in any one of the preceding claims, spacing the first cell wall from a second cell wall to form a gap, and filling the gap with a liquid crystal material.

30. A method as claimed in Claim 29, in which the second cell wall is made by a method as claimed in any one of Claims 1 to 27.

31. A method as claimed in Claim 30 when dependent on Claim 3, in which the alignment directions of the first alignment layers of the first and second cell walls are substantially orthogonal.

32. A method as claimed in Claim 31, in which the liquid crystal material comprises a nematic liquid crystal and a chiral dopant.

33. A cell wall for a liquid crystal spatial light modulator made by a method as claimed in any one of Claims 1 to 28.

34. A spatial light modulator made by a method as claimed in any one of Claims 29 to 32.

The Patent Office

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Application No:	GB 9713627.9	**Examiner:**	David Keston
Claims searched:	1-34	**Date of search:**	8 December 1997

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Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G2F (FSX)

Int Cl (Ed.6): G02F 1/1335; G02B 5/30

Other: ONLINE: WPI INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
Y	US 5049427	BAYER - see page 1	1-4
Y	GB 2296099	SHARP - see para. 2 on page 3	1-4
A	EP 0397263	N.V. PHILIPS' - see page 2	1-4
A	EP 0348964	MITSUBISHI PETROCHEMICAL CO. - see page 2	1-4

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Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
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